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Rotorcraft Night Vision Goggle Evaluation

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Final Report

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Federal Aviation Administration

NOTICE

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**Federal Aviation
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800 Independence Ave S W
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Dear Colleague:

Enclosed is a copy of our recent publication entitled "Rotorcraft Night Vision Goggle Evaluation" (FAA/RD-91/11). This document provides information and assessments on several key issues on the potential use of night vision goggles (NVGs) in civilian rotorcraft missions. The investigation of NVGs is part of an ongoing research effort by the Federal Aviation Administration (FAA) to evaluate various technology applications which might enhance rotorcraft safety in night, visual meteorological conditions (VMC).

Night vision enhancement devices (NVEDs) such as NVGs represent the most economically viable systems that could readily be used in current and near-term rotorcraft operations. Additionally, due to the extensive military training on NVGs in the past ten years, a significant number of civilian helicopter pilots flying law enforcement and emergency medical services (EMS) missions have received NVG training. These two factors: available technology and a trained pilot community, could accelerate requests to use NVGs in civilian operational applications. Anticipating this, the FAA Vertical Flight Program Office has sought to identify key safety and regulatory issues while investigating the advantages and limitations of using NVGs in civilian rotorcraft.

The results of our investigations and analysis of the civil uses of NVEDs are found in this report. This document is neither a basis to allow the civilian use of NVGs nor is it a foundation to preclude such an application of this technology. It is an interim milestone in a fact-finding process which will allow the FAA to make an informed decision on future requests by the public to use of NVGs. It is also part of a long-range research and development process to allow safer and more effective rotorcraft operations in the future.

One of the most revealing findings from our analyses is that the extensive body of knowledge from military use of NVGs is only partially transferable to civilian applications. Since most of the military missions involve tactical operations where stealth and extremely low level flight drive the use and limitations of NVGs, the resulting procedures and equipment designs cannot readily be applied to civilian applications. This gap between military use and potential civilian use raises key safety, economic, and pilot training issues that need to be addressed.

Still, the results of our interviews and discussions with pilots, engineers, and aeromedical experts who have extensive experience in night flying and using NVGs indicate an overwhelming preference to having NVGs available when flying at night in VMC. As a result of this initial effort, and based on the findings discussed in this report, the FAA is continuing its investigation into using NVGs in the civilian sector. Emergency Medical Service (EMS) helicopter operators offer possibly the greatest potential benefit as well as the most critical civilian operational environment for future NVG use. Flight test evaluations will be flown in late 1991 and early 1992 to further address these issues.

James I. McDaniel
Director, Vertical Flight Program Office

Enclosure

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16. Abstract

This document addresses the potential use of night vision goggles (NVG's) by the civilian rotorcraft community. Key issues analyzed are the advantages and limitations of using NVG's in civilian rotorcraft operations, safety factors surrounding NVG use, and pilot qualification/training requirements. Background information on NVG equipment design, characteristics, types, and associated aircraft requirements/modifications are also presented in the context of civilian use. These issues are then related to the existing FAA regulations concerning night flying operations.

Pilots, engineers, and aeromedical experts from the uniformed services, as well as several civil proponents who have had extensive experience with NVG's were interviewed. Their experiences, insights, and recommendations are incorporated into the text. All those with previous NVG experience agreed that despite the limitations, they would prefer flying at night with NVG's available and that NVG's reduce stress and increase situational awareness in the cockpit at night.

This investigation concludes that the civil use of NVG's as an aid during en route and certain terminal operations can increase safety, enhance situational awareness, and significantly reduce the pilot workload and stress normally associated with flying at night. At the same time this investigation highlights that a number of key safety issues, unique to the civilian pilot community, still need to be resolved. A follow-on flight evaluation and simulation effort are envisioned to address these issues.

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1.0 INTRODUCTION

1.1 BACKGROUND

Rapid growth in night vision goggle (NVG) functional capability coupled with significantly improved performance has resulted in a variety of civil operators beginning to consider NVG use. Therefore a need exists for the FAA to evaluate these devices for purposes of determining the requirements for approval for their use in civil aircraft. Night image intensification devices (I^2 devices or night vision goggles) are in widespread use by the military services today, and pilots trained in the use of such systems are now entering the civil sector. These systems present new capabilities, but not without requiring that special consideration be given to the areas of pilot/crew workload, human factors adaptations, specialized training, and unique aircraft configuration requirements, each of which must be addressed specifically as they apply to civil use. The FAA requires technical support in this effort to identify and evaluate the feasibility of the use of night vision devices in civil applications and the technical, operational, and regulatory requirements for approval. The result of this effort is a technical report which contains technical data and guidance material to support those elements of the agency charged with the performance of regulatory actions and the development of advisory materials and standards.

1.2 TASKING

This document reports the results of an 8-month effort by Systems Control Technology (SCT) and Starmark Corporation in support of FAA tasking under contract DTFA01-87-C-00014.

The tasking involved the following:

(a) determining how civil helicopter operators desire to operate or, are operating today with NVG's (this includes the identification of operational advantages, perceived or real);

(b) in context with the findings of (a), research the use of NVG's by military users considering: operations, training, equipment, and maintenance;

(c) identify, in detail, the technical capabilities and limitations of available systems (equipment) installed as well as uninstalled in civil rotorcraft; and

(d) identify training and currency requirements and suggest job tasks to be used by the FAA when considering approval of the use of night vision goggles.

1.3 STUDY METHODOLOGY

1.3.1 Initial Contact and Interview

The initial step in the research effort involved a telephone survey to identify those individuals, firms, and agencies who had either a user or business interest in the civil application of NVG's. Extensive documentation was acquired and several on-site visits planned as a result of the telephone survey.

1.3.2 Facility Visits

A series of visits to potential user activities, night vision device manufacturers, and a variety of laboratory/training facilities was undertaken to acquire as much first hand data as possible. Appendix A provides a list of facilities visited. This effort resulted in a number of briefings, a variety of ground demonstrations, and approximately 3 hours of flight demonstration by interested personnel.

(a) Civil Sector. The objective of the telephone contacts and subsequent visits to the civil sector was to determine the types of flight operations civil rotorcraft operators would propose using NVG's, to determine the user's anticipated benefits, and to evaluate any limitations associated with NVG use.

(b) Military Sector. The objective of the telephone contacts and visits to the military sector was to determine what experience and technical data could be made available to the FAA which would aid in understanding the safety issues associated with NVG use and in determining future regulatory requirements.

(c) Industry. United States rotorcraft manufacturers were contacted to determine their position concerning:

1. NVG use by civil operators,
2. NVG cockpit compatibility
   - minimum safe modifications
   - future design possibilities,
3. NVG training requirements, and
4. illuminating devices available/compatible with NVG's.

Equipment manufacturers were surveyed to determine their views and concerns relative to:

1. cockpit interface requirements,
2. maintenance of NVG's and associated equipments,
3. preflight requirements, and
4. any additional topics.

1.3.3 Team Background

The study team was comprised of members who had experience in the following areas:

- o Navy,
- o Army,
- o Air Force,
- o FAA, and
- o civil.

1.3.4 Analysis

The analysis concentrated on establishing the night operational needs of the civil helicopter pilot during the accomplishment of civil helicopter tasking. The information obtained by telephone, by personal contact, and during flight operations was used, along with the experience of the study team, to build a generalized concept of operations and related functional needs of the civil pilot. The emergency medical service (EMS) segment of the civil community, because of their 24 hour operation, became the primary focus for the analysis. The results of this effort were informally shared with several experienced civil helicopter pilots to improve, through an iterative process, the concept of operation, postulated needs, and related benefits. The results were then presented to highly experienced military pilots and other government/industry experts for their reaction. In most cases, these individuals were initially reluctant to personally approve civil NVG use. However, their reluctance to approve of civil NVG use often changed as the civil application was further discussed. Many pilots related personal or unit experience which did in fact support the logic of civil NVG use by suitably trained and equipped personnel. These inputs required real time analysis, again resulting in what might be characterized as a process which iteratively improved the concept of safe civil NVG helicopter operations and a better understanding of the related technical, operational, and environmental factors. The analysis led to this report which is structured to provide FAA officials who lack NVG expertise with the information and references required to assist in developing rational and timely operational regulatory decisions.

2.0 CIVIL OPERATOR OBJECTIVES

2.1 INTRODUCTION

This section summarizes the observed and postulated civil operator NVG objectives which could be determined within the scope of this study.

In summary, there are two classes of non-military operators; the pure civil or commercial operator and the para-military group, which includes a variety of law enforcement agencies, the Drug Enforcement Agency (DEA), U.S. Coast Guard, etc. Both groups are very interested in the FAA's involvement and guidance concerning NVG's. The efforts reported in this document, however, were focused only upon the pure civil operator and related objectives. When considering the application of night vision goggles to civil rotorcraft operations, it was quickly apparent that civil operators are not interested in expanding the operating envelope now available under current regulations and approved operational procedures. The principal objective of all operators is the improvement of flight safety. They recognize that they can currently legally and safely operate at night, but that they cannot see as well at night as they can in the daytime. They also know that they can see better with NVG's at night than they can without NVG's. They believe that the improved visibility provided by NVG's will allow them to see the terrain ahead of and along their flight path, improving both navigation and their ability to see and avoid terrain, wires, and other obstructions. They believe that they can use NVG's to aid in detecting and identifying objects and terrain features which they can see in no other way. Additionally, in an emergency, NVG's may be helpful in the selection of an emergency landing site.

The helicopter community is not as unified on the use of NVG's to land and take off. Many would prefer to use conventional searchlights, landing lights, spotlights, etc., with which they are more familiar and which provide adequate illumination.

NVG's therefore have two potential applications. The first is to use NVG's only during the en route phase of flight. The second application is to continue to use NVG's for the approach (and departure) with the transition to unaided flight being performed as late as just prior to a hover. An inferred option is to rapidly revert back to NVG's in the event the approach is aborted.

2.2 SUMMARY OF CIVIL OPERATOR OBJECTIVES

Figures 1 through 3 are included to expedite the reader's understanding of the civil operator's operational objectives as determined by the study. These graphics were developed as composite characterizations of the perceived objectives of both civil helicopter pilots and operators.

Figure 1 illustrates the en route operation and depicts how civil helicopters fly at night, with or without NVG's. The pilot uses standard operating procedures to establish a route which is 5 to 10 miles wide. This path may be bounded by hills or other obstructions but has a floor which is not penetrated by any obstruction. NVG's in this case would provide a much clearer horizon delineation which facilitates heads-up VFR flying and enables the pilot to better locate and identify navigation landmarks (roads, lighted towers, cities, rivers, lakes, bridges, etc). Standard operating procedures and FAA regulations dictate clearance from clouds and visibility requirements.

In figure 2 the crew uses NVG's to help locate the site. In the emergency medical service case the emergency lights of public service vehicles can be seen with NVG's for miles before any other indicator. Arriving at the site, the pilot sets up a high reconnaissance pattern to look for obstructions and obstruction indicators such as power line rights-of-way cut through the woods as shown. As the aircraft descends, and while monitoring the radar altimeter, the pilot turns on available floodlights, controllable spotlights, and sometimes powerful searchlights and scans the hilltops, ridges, and road sides for additional telephone poles, wires, and other obstructions. During the descent, pilots utilizing NVG's must be alert to the fact that, while NVG's provide an enhanced view of the landing area, surrounding obstructions, and terrain, there is a tendency for object fixation requiring strict scanning discipline. At the same time, depth perception limitations resulting from the two-dimensional presentation and restricted field of view require monitoring of the radar altimeter to help provide the third (depth) dimension.

In figure 3 the pilot's approach and departure plan is laid out. Having observed the wind, the pilot selects an approach path and a departure path. The departure path will also serve as an emergency egress route in case of an emergency or ground wave-off of the approach. The approach is oriented so as to remain, if possible, within 90 degrees of the wind during approach and departure. Upon reaching a point where the external lighting becomes sufficiently effective, the NVG's may be flipped-up (goggles are hinge mounted) and the approach continued unaided. A technique of looking-under the goggles for outside viewing may be as effective and operationally acceptable as flipping-up, although the issue of focusing for pilots wearing bifocal glasses requires evaluation. Proper wearing of goggles, look-under capability, and scanning techniques are addressed in section 4.0.

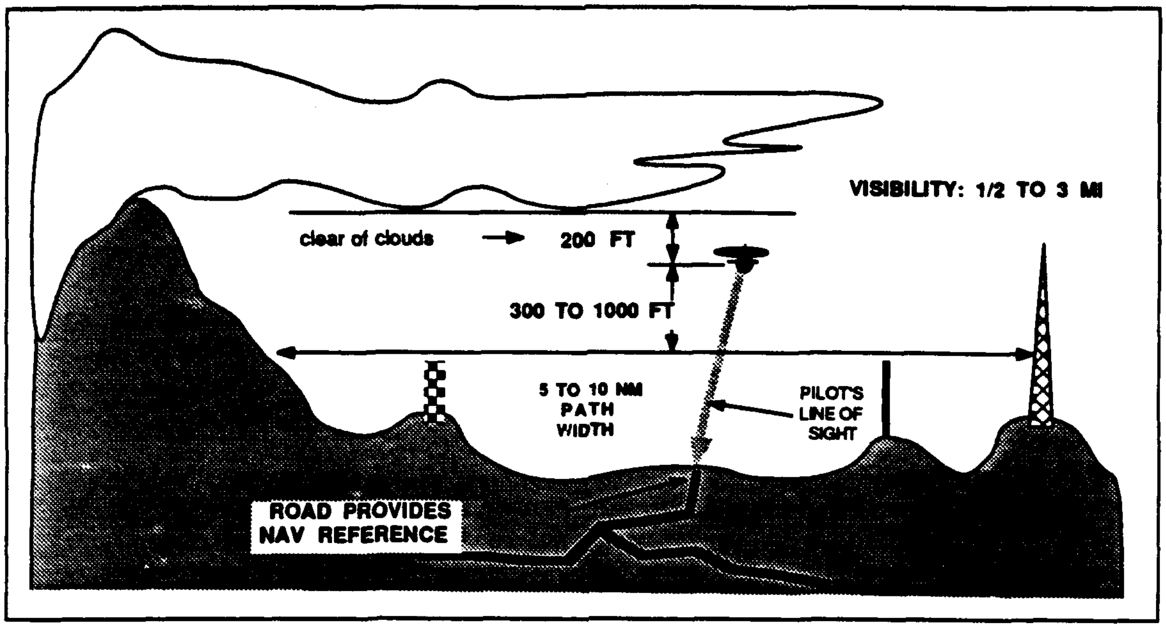


FIGURE 1 CIVIL NIGHT EN ROUTE OPERATIONS

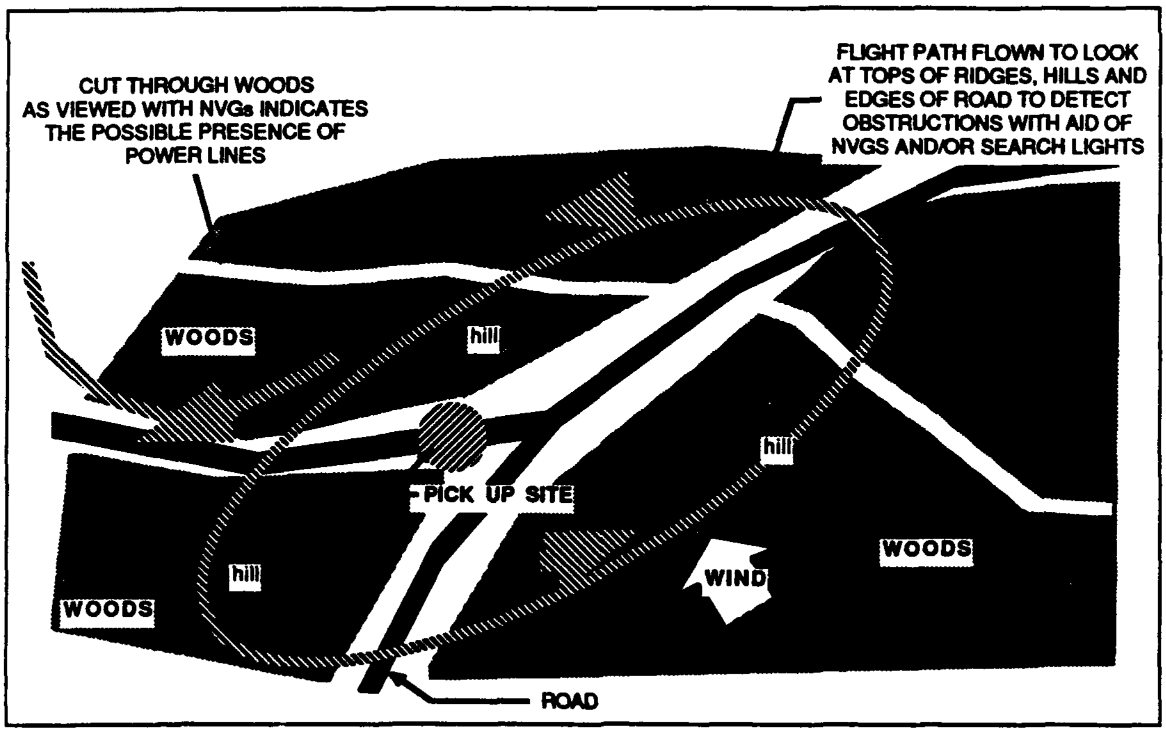


FIGURE 2 OVERFLIGHT OF TERRAIN ALLOWS CREW TO LOCATE OBSTRUCTIONS AND SELECT APPROACH AND DEPARTURE PATHS

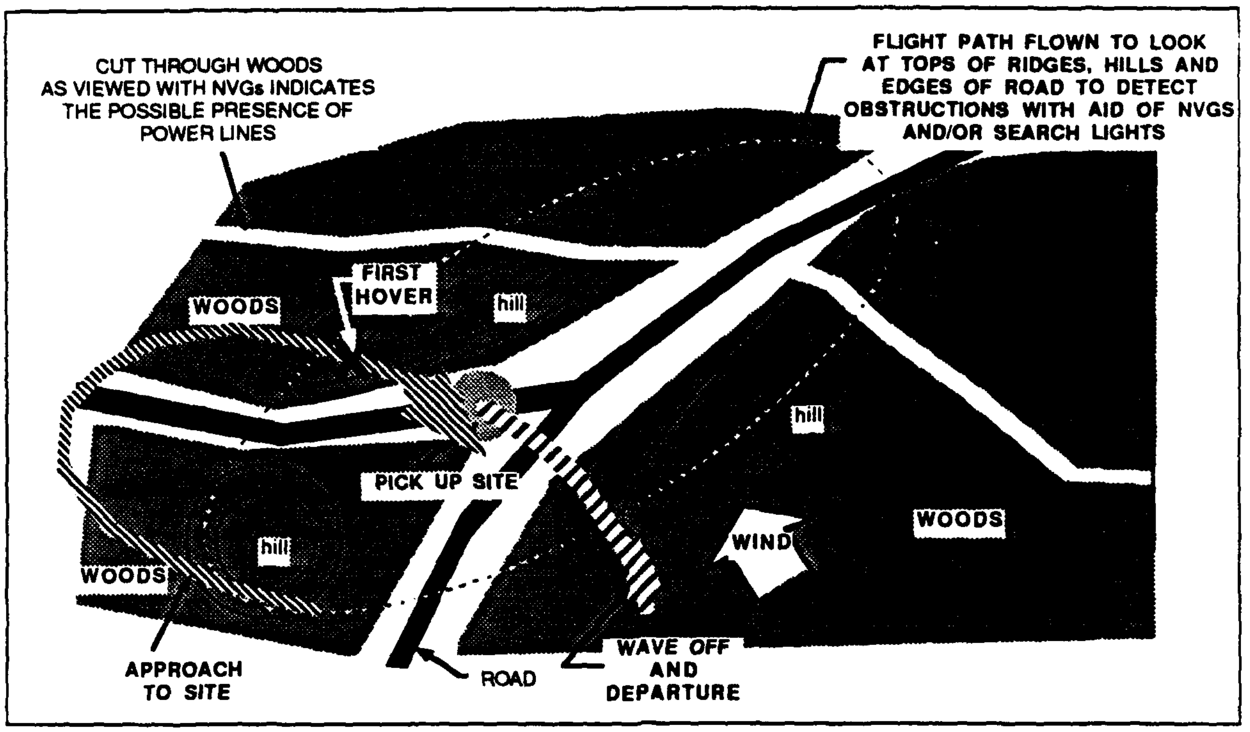


FIGURE 3 TYPICAL APPROACH & DEPARTURE PATHS

3.0 EQUIPMENT CHARACTERISTICS

3.1 INTRODUCTION

This section summarizes information concerning the basics of NVG design and pertinent operational considerations. The analysis revealed that there is a wide range of NVG's available.

3.2 OFFICE OF THE SECRETARY OF DEFENSE (OSD) REVIEW OF TESTING

A reprint of the OSD review of testing is contained in appendix B. This review provides a brief but comprehensive overview of the history and characteristics of NVG's used by the military. Examination of this review is recommended prior to further reading. Excellent detailed descriptions of the NVG's are also found in refer 2, 3, and 4.

3.3 DESCRIPTION

The principal component of all night vision enhancement systems is the image intensifier tube. These tubes detect minute amounts of blue, green, and red visible waves and certain invisible infrared (IR) waves. When these minute amounts of light energy (photons) strike the photocathode in the image intensifier tube, the photocathode releases electrons. These electrons are then multiplied thousands of times by means of an electron multiplier called a micro-channel plate and are routed onto the tube's phosphor screen. The phosphor screen emits a green light each time it is struck by an electron. Because the phosphor screen emits light in the exact pattern of the photons that strike the photocathode, an image is reproduced. Thus the picture delivered to the user has been converted from a very small amount of visible and/or invisible light, to accelerated electrons, and back to visible light. The amount of "light" amplification produced in an image intensifier tube is referred to as the device's gain (reference 4).

3.4 NIGHT VISION GOGGLES, GENERATION I, II, AND III

Generally image intensifier technology (or I^2) is referred to in terms of first, second, and third generation systems. Most first generation tube devices are about a foot long, require relatively high voltages and wash-out or bloom very easily. First generation tubes are not used in aviators' night vision goggles. Both second and third generation tubes (GEN II and GEN III) are used in varying applications. Both are small and lightweight, with two primary differences: the GEN II uses a multi-alkali photocathode while the GEN III uses a gallium arsenide (GaAs) photocathode with a metal oxide film added to the micro-channel plate. The results of these GEN III modifications are significant. This resulted in acceptable performance when the only ambient light source is starlight, and a service life extended from 2 to 4 thousand hours to over 10 thousand hours. The GEN III tube is far more sensitive in the regions where the invisible IR radiation from the stars is plentiful. In this sensitivity range the photon generation rate is five to seven times greater than that found in the visible light range. References throughout this document to GEN II^{plus} are to high performance level GEN II NVG technology which achieves higher gain and output brightness than standard GEN II systems.

Essentially, both second and third generation devices work equally well in high ambient light levels (i.e., full moon overhead with no obscurations). However, under overcast starlight conditions the GEN III devices are far superior (reference 4). This is hardly surprising in that the gain of a GEN II device is about 10,000 versus 25,000 for GEN III.

Because of the high gain and accompanying sensitivity of GEN III, there are conditions under which GEN II's can provide greater contrast than GEN III's. In a comparative visual performance study between GEN II and GEN III, the Air Force discovered that in a desert environment, under high ambient light conditions, GEN II's permitted viewing of a road when the GEN III's did not. Because the GEN III image intensifiers were equally sensitive to the road and its surrounding foliage, there was no contrast gradient, and therefore no visual discrimination between the two. The study concluded that this was due to the enhanced response of GEN III in the IR part of the spectrum. The GEN II could, however, discriminate the roadway from the surrounding terrain because its intensifiers were not as sensitive to the weak IR light that the road reflected. The spectral radiation reflected from the road surface did not elicit a response from the GEN II, so it was seen as essentially dark, while the surroundings were clearly distinguishable. In effect, the roadway was detected by the GEN II, not because the system was sensitive to the road, but because it was sensitive to the surroundings. Conversely, the GEN III did not allow discrimination of the roadway because it was equally sensitive to both the road and its surroundings. This phenomenon only occurs in unique ambient light conditions, but helps to illustrate why some users have expressed a preference for the GEN II, even though the GEN III is generally recognized as a superior system (has a higher gain and wider light spectrum).

Although an abundance of night vision goggle type devices are available, only the GEN II-AN/PVS-5A, B/C, (with modified faceplate) and GEN III-ANVIS (Aviator's Night Vision) systems were deemed the appropriate focus for discussion by all persons interviewed. There is apparent universal agreement that an ANVIS-type (referring to design and mounting) system be utilized, regardless of whether a second or third generation tube is used. This ANVIS-type system includes an AN/AVS-6 breakaway frame, dual battery pack, and low voltage indicator. Essentially the only difference might be the tube utilized (reference 4). The ANVIS system can be either helmet mounted or worn using a light-weight head mount (reference 3).

Currently only ITT Corporation is producing GEN III goggles (ANVIS) for the military, with Litton Corporation being the only other manufacturer that has met the military specification (MILSPEC) requirements (Mar 90) for the tubes.

ITT has also developed a proposed civilian specification for NVG's. Of particular interest in the analysis were the differences between the MILSPEC and the ITT proposed civilian specification. These differences lie in four areas, all confined to the image intensifier tube. The first three areas are claimed not to be discernable to the user. The precise details of the differences are quite technical and will not be discussed herein. The differences are:

1. an approximate 10 percent reduction in photocathode sensitivity,

2. a reduction in uniformity of screen brightness (approximately 25 percent for bright objects and 10 percent for dim objects),

3. higher background noise, and

4. more/larger cosmetic imperfections, i.e., dark and/or continuously emitting spots.

It was emphasized by ITT that a rejected MILSPEC image intensifier tube can in many instances meet the proposed civilian specification, and in fact out perform, in terms of image presentation, a MILSPEC tube. The example used was of a tube that had a single dark spot or one too many dark spots in an area that the MILSPEC would not allow. It would however meet the proposed civilian specification. This goggle could have very high sensitivity, near perfect output brightness, and virtually no background noise thus providing superior performance as a civilian model (references 23 and 25). The Air Force has in fact, on occasion, knowingly purchased tubes with such spots because they were otherwise of extremely high quality.

Also of significant importance is the minus-blue light filter found in the GEN III tubes. In effect this filter makes a certain spectrum of blue light invisible to the tube thus allowing the use of non-interfering blue lighting in the cockpit (see section 6).

Presently the cost of a GEN II NVG is approximately $9,000.00. The cost for a GEN III NVG is approximately $15,000.00 (reference 25).

4.0 PILOT-NVG VIEWING INTERFACE

4.1 INTRODUCTION

This section deals with the ability of the pilot to alternately and simultaneously see through and around an NVG device.

4.2 ANALYTICAL OBJECTIVE

A pilot flying a helicopter at night, when using NVG's in visual meteorological conditions (VMC), must be able to maintain the same (or better) level of situational awareness as is possible during unaided flight. To accomplish this objective the pilot must have the capacity to see inside as well as outside the cockpit (figure 4). The following analysis provides basic insight into the pilot viewing process.

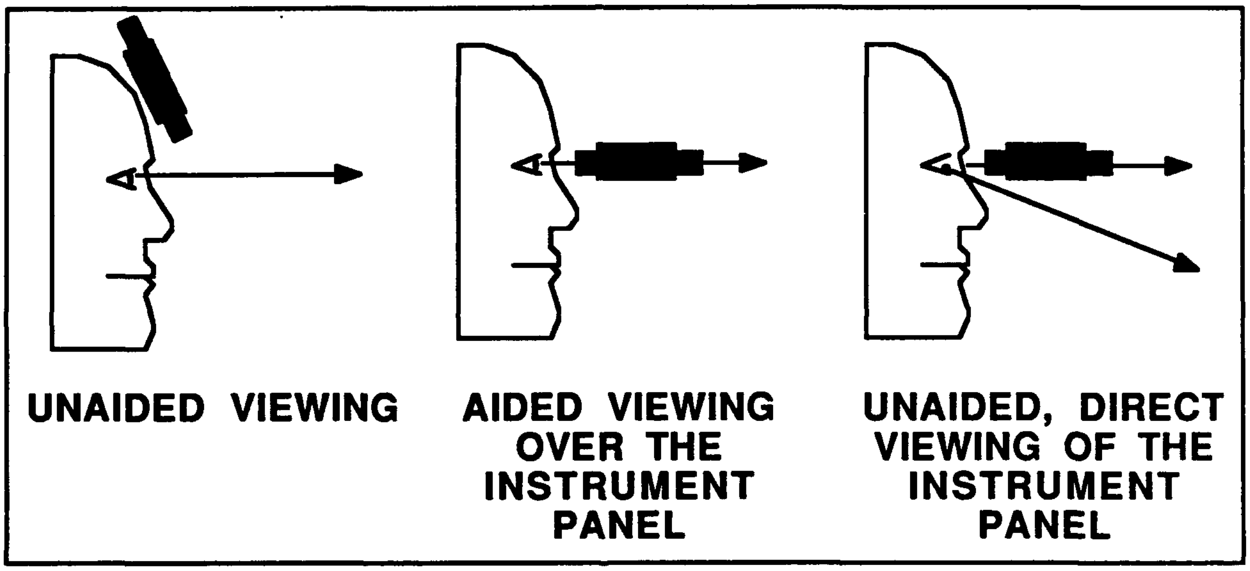


FIGURE 4 PILOT'S VIEWING ALTERNATIVES

4.3 BASIC MODE OF OPERATION

The pilot views the outside world by adjusting the device so that both eyes can see straight ahead, through the device, to the outside world.

With the device adjusted as illustrated, the pilot can also look down, under the eyepieces at the instrument panel, through a "chin" window, or out a door/side window. It is also possible to tilt the head back to see out over the instrument panel with the unaided eye, depending, to a certain extent, upon seat position, aircraft instrument panel design/configuration, and whether the pilot wears corrective lenses. This is a viable alternative for brief looks to conduct an unaided vision cross-check of an NVG detected image.

4.4 FIELD OF VIEW

Looking in any given direction, the properly adjusted devices provide approximately a 40 degree field of view (FOV). If the device is adjusted so that the eyepiece is substantially greater than 1 inch from the eye, the field of view decreases. There may also be some minor loss in detail for such adjustments (figure 5). Some pilots prefer the tradeoff of a smaller field of view for a larger field of regard and fly with the eyepiece positioned beyond 1 inch from the eye.

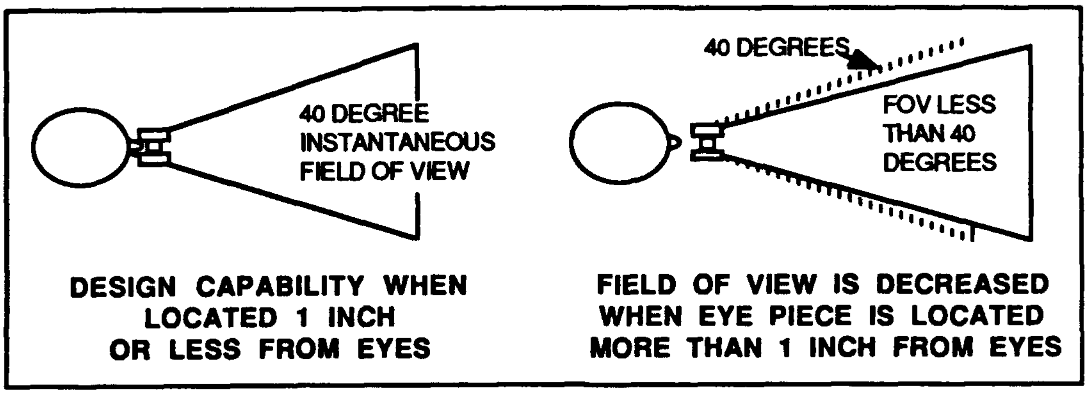


FIGURE 5 PILOT FIELD OF VIEW WITH NVG's

There are, however, some pilots who expressed a preference to adjust the device so that the eyepiece is beyond 1 inch thereby increasing the unaided, inside-the-cockpit viewing capability. This procedure, which may or may not be prudent, requires further study in order that the FAA might understand the associated risks and safety issues involved.

4.5 FIELD OF REGARD

An unaided pilot can scan with simple eye movement from right to left, and up and down without moving his/her head. For NVG aided operations however, the pilot can only scan outside the cockpit within the 40 degree FOV available at any instant. The pilot must turn his/her head to see through a greater arc. This head motion defines the aided field of regard (figure 6). The aided pilot must move his/her head to the right and left to gain the full situational awareness benefits provided by NVG's. This head motion requires a trained discipline similar to that required for conventional instrument flight operations and for certain confined area operations under difficult visual conditions. Cockpit instrument field of regard is unchanged using unaided viewing under and around the NVG's. An effective and disciplined pattern of internal and external, aided and unaided, viewing is essential.

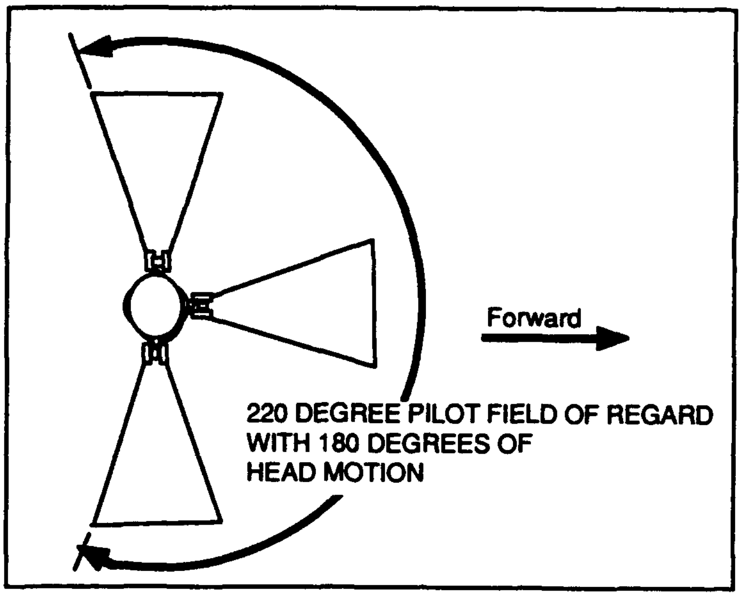


FIGURE 6 PILOT FIELD OF REGARD WITH NVG's

4.6 COMPOSITE FIELD OF VIEW

Figure 7 illustrates how the NVG housing and associated attachments may interfere with unaided viewing. It also indicates the potential for unaided peripheral viewing while at the same time being able to look forward through the device. The peripheral capability may be somewhat diminished below normal unaided capability because of the pilots' concentration on the NVG image, cockpit lighting, and the sensitivity reduction induced by the goggles. Regardless, it is clear that cockpit warning lights and other such strong cues are clearly detectable through simultaneous aided direct viewing and unaided peripheral viewing. In addition the pilot's eyes (one or both) can scan outside the aided FOV, and look directly at the instrument panel or some object outside the aircraft. While the eyes have a deflection limit which limits the pilot's ability to alternately look around the NVG devices, this capability is available and easy to utilize.

4.7 COCKPIT ENVIRONMENT

All cockpits are different but, in general, helicopters have a great deal more window glass than similarly sized fixed-wing airplanes. Conversely, the instrument panels and consoles of the two types of aircraft are very similar. Figure 8 illustrates the basic scan from the right seat (pilot-in-command) position. The scan to the right and left involves slow deliberate head movement, with momentary pauses to either look at the instrument panel or to observe an NVG image. The head moves, stops; the eyes move, stop; the eyes move again, stop; the head then moves again, and the cycle continues. When the pilot desires to perform a near field, unaided viewing task (such as landing at a prepared, well-lighted heliport), he/she may flip the goggles out of view or simply reposition his/her body in the seat to allow the scan to alternate between a near-field unaided scan, a far-field aided scan, and an inside-the-cockpit scan. Each of these three scans yields unique and useful information.

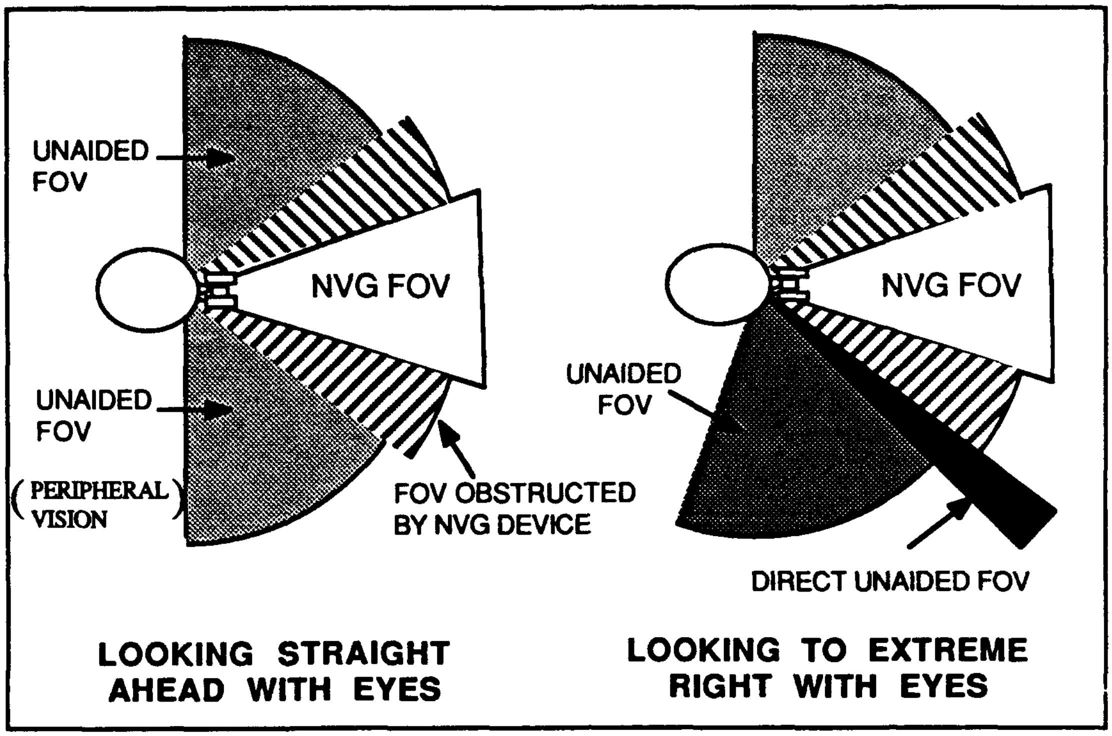


FIGURE 7 PILOT'S COMPOSITE FIELD OF VIEW WITH NVG's

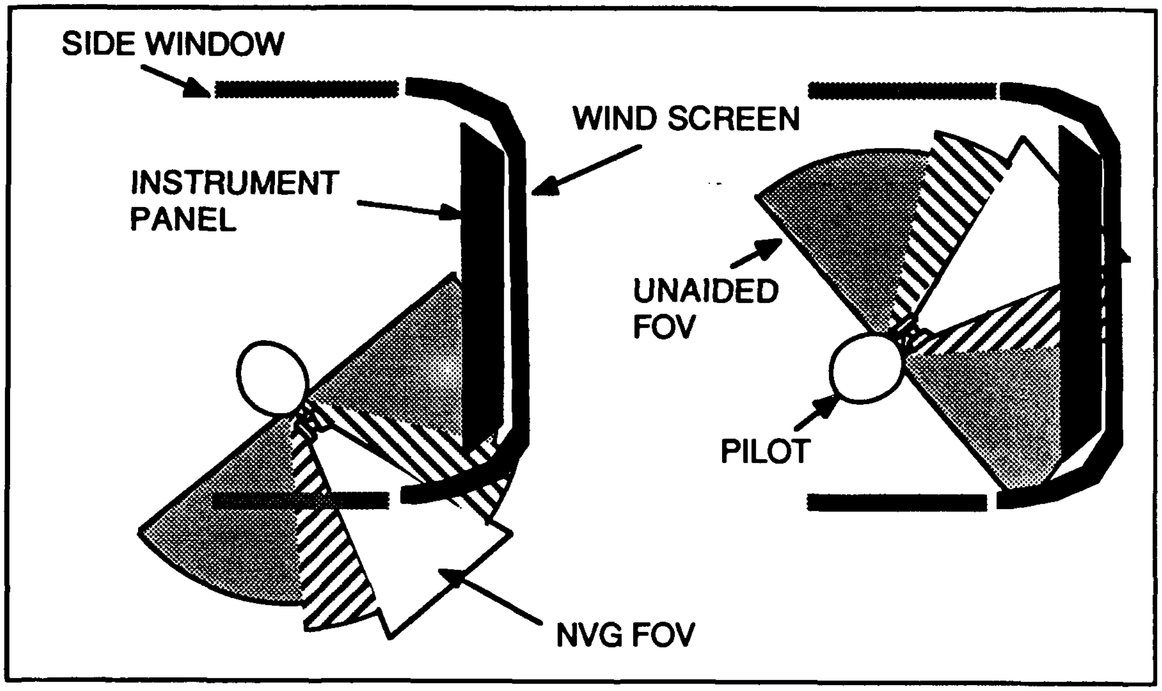


FIGURE 8 PILOT FIELD OF REGARD IN COCKPIT ENVIRONMENT

5.0 RELATED MILITARY EXPERIENCE

5.1 INTRODUCTION

This section summarizes the responses of the military pilots, engineers, and aeromedical subject matter experts interviewed throughout the evaluation.

The study found that the military operator is using NVG's to accomplish tasks which could not otherwise be undertaken. They are mission enabling devices. An example of this would be the extended operations conducted intentionally below the tops of the trees called "nap of the earth" flight or NOE. However, further search into the operational experience of the military revealed common threads with proposed civil application. Also, the search produced extensive analyses of accidents when NVG's were in use.

There were a number of issues to be addressed which are common to both: cockpit interface characteristics, the requirement for proper training, the handling of inflight emergencies, the need to avoid wires and towers en route, and the need to be aware of and be able to react to goggle failure. On the other hand, the loss of situational awareness while operating in close proximity to known obstructions and/or other aircraft (tactical formation or several aircraft operating from a common point) appeared to be the most common contributing cause in military mishaps when NVG's were in use. This situation did not appear to have much commonality with the expected civil operations.

5.2 OFFICE OF THE SECRETARY OF DEFENSE REVIEW OF TESTING

A reprint of the OSD review of testing is contained in appendix B. This review provides an excellent description of Army, Navy, Air Force, and Marine aviation night vision goggle training programs. Therefore, only information not contained in the review will be presented in this section.

5.2.1 Army

Although the preponderance of Army operations bear little resemblance to that of the civil operator, some NVG mission applications are very similar to proposed civil flight profiles. At the Aviation Training Brigade, Fort Rucker, AL, it was pointed out that units in Alaska have been flying well above terrain flight altitudes with NVG's for at least 5 years. These units typically fly at 1,500 feet AGL and still find the NVG's to be an invaluable aid to navigation, situational awareness, and obstruction avoidance. Even at altitudes as high as 8,000 feet the NVG's were considered to be a valuable asset. These units would normally file instrument flight rules (IFR) to get proper handling and navigation assistance for obstruction avoidance. Even at the IFR required altitudes the NVG's provide a clear picture of the terrain over which they were flying which could not be seen when flying unaided. Anti-collision lights are kept on and do not interfere with the goggles.

5.2.1.1 Findings

A consistent theme echoed in all of the Army interviews was that after an aviator became accustomed to the additional situational awareness provided by night vision goggles, he or she would feel uneasy flying at night without them. (These comments did not refer to the no-longer-used full face goggle (AN/PVS-5A)). "Why would anyone want to fly at night without taking their goggles?" was the commonly heard question. Without exception, all Army personnel interviewed agreed that the key to obstacle avoidance is knowing where you are in a routinely flown operating area or in relation to a properly marked aeronautical chart.

The U.S. Army Safety Center at Fort Rucker provided accident statistics and lessons learned (see reference 13). NVG accident rates do not appear unique in comparison to the Army's overall accident rate. For example, UH-60's have had wire strikes during the day and at night, both aided and unaided. Despite extensive use, there is no evidence of any NVG accident outside the NOE flight mode. It is extremely difficult to attribute an accident solely to the fact that NVG's were being worn. The only exception noted was a goggle failure (battery) which resulted in an AH-1 Cobra accident. This accident resulted in a requirement for mandatory use of a dual battery pack. Most accidents involving NVG's were the result of a diversion of the pilot's attention during critical terrain flight operations.

5.2.1.2 Additional General Comments

The following comments are provided for additional information.

- At both the Directorate of Evaluation and Standardization, Fort Rucker, AL, and the Night Vision Laboratory, Fort Belvoir, VA, it was emphasized that in most cases, unaided night flight was far more stressful than aided night flight.

- The Army does authorize single-pilot NVG flying (including terrain flight) in unique circumstances and with their best pilots (i.e. Night Vision Laboratory pilots, certain elements of Task Force 160).

- The program managers at the Night Vision Electro Optics Laboratory, Fort Belvoir, VA, volunteered to aid in conducting technical evaluations upon request from the FAA.

- As of 20 July 1989 the Army has had 415 Class A helicopter accidents. Of these, 320 occurred during the day and 95 occurred at night. Of these night accidents, 41 occurred with goggles in use.

- In order to fly using NVG's with the moon at less than 30 degrees and/or 23 percent illumination, aircraft must be fitted with an operational IR searchlight. There are no specified procedures or requirements for its use, but it must be available.

- If GEN II, GEN II^{plus}, and GEN III are approved for use, the training required will be different due to the differences in performance.

- In dual piloted operations, both pilots must wear the same model NVG's so that they have the same visual reference cues.

- The curve of the windscreen on the OH-58 (Bell 206) results in a great deal of internally reflected light. Cockpit compatible lighting is extremely important (reference 21).

- The Army is currently researching night adaptation time after using NVG's and illusions associated with takeoff and landing and NOE operations, i.e., landing in a pit, difficulty discerning slopes, etc.

- Treat all dark areas and shadows as obstacles. Army night flight techniques and procedures are found in TC 1-204 (see reference 13).

- While the Army requires one NVG flight every 45 days to maintain currency. It was strongly emphasized that the issue is proficiency, not currency.

- The radar altimeter helps provide a depth dimension during NVG flight, a dimension that is essential to terrain flight, approach, and departure operations.

- Electromagnetic interference (EMI) would need to be looked into in the civil operation due to the increased use of glass cockpits (observation).

- A relationship exists between day VFR flight and night aided flight. Flying with goggles is still visual flight. A good instrument pilot does not equate to a good goggle pilot, and vice versa.

5.2.2 Marines

The Night Imaging and Threat Evaluation Laboratory (NITELAB) at Marine Corp Air Station, Yuma, AZ reinforced the data obtained from the Army. Of key importance was the value of training using a terrain board. The terrain board is a mockup that depicts a wide variety of topographical features that might be encountered in flight, coupled with the capability of varying light position and intensity. The terrain board is used to illustrate shadowing, low contrast situations, good and poor light source angles, NVG gain capability, etc. The only other known terrain board is at the U.S. Coast Guard facility at Mobile which was modeled after the one at NITELAB (reference 16). Aviators with over 1,000 hours NVG time before seeing the board for the first time, expressed a sincere appreciation for what this training aid had taught them. Without exception, all personnel interviewed agreed that a terrain board was an exceptional enhancement to any NVG training program.

5.2.2.1 Similarities to Expected Civil Applications

Marine Rescue uses an NVG flight profile nearly identical to the proposed EMS profiles, essentially using the NVG's only during the en route phase of flight (typically above 300 feet AGL). Prior to an approach a night sun flood lamp or similar high power lighting device is activated and the operation continues unaided. Some of the pilots interviewed expressed a preference for keeping the goggles in place (all have the option) and merely looking underneath during the approach and landing phase. In the event of an abort the aviator simply transitions back "up" into the goggles. Marine rescue pilots believe that the NVG's afford them a much improved situational awareness; this includes the ability to see weather and avoid it, to see and avoid approaching traffic early on, to provide for more precise navigation, and under most conditions to provide a visible horizon.

5.2.2.2 Additional General Comments

The following are provided for additional information.

- Marine rescue pilots recommend and use normal landing and searchlights for all non-tactical NVG application (in lieu of IR light).

- To determine that adequate light is available to support NVG use, NITELAB uses a program almost identical to the one established by the U.S. Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM (reference 17).

- At terrain flight altitudes, lower airspeeds than day flight are required to allow adequate time to mentally process the visual cues provided by the NVG's. Night flight techniques and procedures are found in the USMC Night Vision Goggle Manual (reference 14).

- The U.S. Marine Corps is acquiring three more terrain boards.

- During normal training, 0.0022 LUX (23 percent moon at 30 degrees above the horizon equivalent) is required for both GEN II and GEN III goggles to be utilized. A notable exception is for deployed personnel. These personnel use only GEN III, AN/AVIS-6's and commanders can authorize flight during no moon conditions. The only requirement is for clear starlight.

- o Spotlight slew rate is slow, limited to about 10 degrees/second and may have travel limits. However, scanning the field of regard with NVG's can be disciplined yet random, relatively quick, and can cover an area limited only by design of the cockpit.

5.2.3 Navy

Although other Navy training facilities do exist, it was determined that the primary naval expertise in the area of helicopter NVG operations was co-located and assigned at the Marine training facility in Yuma (MAWTS-1).

5.2.4 Air Force

Air Force helicopter NVG operations are primarily restricted to Special Operations units. A central location for training similar to the Army, Marines, and Coast Guard does not exist. An interview at the 20th Special Operations Forces (SOF), Hurlburt Field revealed extensive Air Force NVG use, but it did not correspond well to civil operations (references 27 and 28).

5.2.5 Coast Guard

Helicopter pilots are the principal users of NVG's in the Coast Guard. Training began with NVG's in 1986, with only GEN III, AN/AVIS-6's being utilized. A methodical evaluation of all existing training programs of the other services was conducted prior to program initiation, with the best parts of each of the other services programs being combined into the Coast Guard program. The entire NVG startup was initiated by a former high-time Army, now Coast Guard, NVG pilot. It is a relatively small but well executed operation.

Three levels of NVG use have been established by the Coast Guard. Level 0 designates personnel not at the flight controls who perform search, scan, surveillance, etc. Level 1 is for pilots authorized en route use of NVG's, not below 300 feet. Level 2 is for the drug interdiction mission and is similar to the Army's tactical use of NVG's. Only one unit, based in Clearwater, FL, currently maintains Level 2.

The Coast Guard was clearly the branch of service conducting flight operations most closely aligned to proposed civilian applications. For this evaluation, Level 1 was deemed the most germane and unless otherwise noted, will be the level referred to throughout the remainder of this review. H-3's are the only aircraft flying Level 1 or 2 at this time.

5.2.5.1 Similarities To Expected Civil Applications

The Coast Guard rule concerning flying with NVG's is: NVG's will be worn only in a flight environment that could also be flown unaided. If the flight would not or could not be made without the NVG's, then that flight will not be authorized. The Coast Guard philosophy is that NVG's decrease the risk and stress of night flying until the point is reached that unaided flight would not be attempted. This philosophy emphasizes that NVG's are an aid, not an enabling device. Goggle failure is not considered an emergency because in the Coast Guard flight profile more than ample time is available to snap the goggles up and continue flight unaided.

5.2.5.2 Training

Coast Guard training methodology is comprehensive, pragmatic, and clearly defined. They utilize the most superior visual training aids evaluated. As with the other services, Coast Guard pilots are required to pass both oral and flight evaluations to become NVG qualified. Crews are evaluated annually with a proposed change to once every 6 months expected in the near future. Their training videos, syllabus and currency requirements are contained in references 5 and 16 and videotapes A through D.

Particular attention should be given to the design and use of a terrain board similar to that being used by the Coast Guard (reference videotape D, "The U.S. Coast Guard Terrain Board"). It is without question a model that could easily become the standard for both civil and military use. Its total cost was less than $16,000 installed. A myriad of light and terrain profile simulations can be demonstrated and valuable lessons learned in less than an hours use. Similar actual aircraft exposure to the variety of simulations capable of being presented is estimated to require 50 hours or more. The terrain board reference tape is an indispensable adjunct to this report.

5.2.5.3 Cockpit Modification

The cockpit lighting modification to the Coast Guard H-3 aircraft was completed at a cost of just under $2,500 by Glareban Inc. This modification consists almost exclusively of filters and eyebrow lights. Bezel lights are recommended but increase the cost. The personal opinion of the Coast Guard representative was that "floodlighted cockpits with filters alone are not adequate."

5.2.5.4 Crew Rest

The Coast Guard has not adopted any new crew rest policy for their NVG qualified pilots. They believe that in their mission, goggle use actually reduces stress and fatigue and therefore does not require increased crew rest. The Army increases their crew rest requirements, but their aviators are flying in a much different and highly demanding environment where night vision is essential to mission prosecution (i.e. low level, contour, and NOE).

5.2.5.5 Additional General Comments

The following are provided for additional information.

- o There have been no Coast Guard NVG accidents since start up.
- o Crews strongly emphasized that they would much prefer to fly with NVG's available at night.
- o They discourage the use of goggles in high traffic/ambient light areas (vicinity of airports, cities, etc.).
- o NVG's enhance pilot ability to detect and avoid clouds.
- o The ability to see the horizon is definitely reassuring.
- o Goggles perform poorly in falling snow and in some situations provide limited feature differentiation due to poor contrast in snow covered terrain.

5.3 KEY POINTS OF AGREEMENT

- o It is a much easier task to transition to NVG flight than it is to transition into IFR flight. The example IFR condition used was an instrument takeoff into a 200 foot ceiling.
- o It is much less stressful to fly using NVG's than it is to fly unaided.
- o The limited field-of-view and the ability to scan throughout the field of regard when using goggles is preferred to the limited ability to see in the field of regard when unaided.
- o Without exception, all aviators that were interviewed would rather fly using the goggles than to fly unaided.

6.0 ANALYSIS OF COCKPIT COMPATIBILITY FOR CIVIL OPERATIONS

6.1 INTRODUCTION

Internal cockpit lighting is that system of lighting located in the cockpit for the purpose of illuminating instrument displays, switches, emergency engine controls, and circuit breakers. A military specification (reference 21) has been developed for application to both old and new helicopters. However, the specification, when applied to civil use, would be more applicable to new production aircraft than to retrofit for the type of operations discussed in this report.

6.2 OBJECTIVE

The objective of any cockpit lighting adaptation to permit NVG use is to ensure that the result is safe for both aided and unaided operations. Normal night operations where the pilot views objects in the cockpit and outside the aircraft without enhancement of any kind is called "unaided viewing."

6.3 REVIEW OF UNAIDED VIEWING

6.3.1 Cockpit Lighting

The color of cockpit lights used for unaided viewing has varied over time from red to white to blue. The most important thing that has been learned is that red is not the preferred color and is no longer used by todays designers.

6.3.2 Intensity

Pilots have controls which allow them to brighten or dim the cockpit lighting environment. Selected settings are based upon training, phase of flight, type of operator, proximity to other ambient light sources, and individual preference. The brighter the lights are in the cockpit, the better the pilot can observe the features in the cockpit. Alternately, as the cockpit lighting level is decreased, the pilot's ability to see outside is enhanced. As with unaided night flights, cockpit lights should be dimmed to the lowest illumination that permits pilots to safely operate inside the cockpit.

Illumination levels from external sources have the opposite effect on the pilot. As the brightness of the external lighting is increased, the pilot may be unable to read dimly lit flight instruments. This is best illustrated by the situation where the pilot is heading into the landing light of another aircraft during taxi operations, or where hovering near the reflected spot of an aircraft search light or ramp floodlight.

6.4 NVG COMPATIBLE LIGHTING

6.4.1 Definition

Cockpit lighting should allow the pilot to read all instruments and panel markings which would ordinarily be visible during conventional unaided night operations. To be NVG compatible, this light must not measurably interfere with the pilot's view through the NVG's.

It is important to recognize that all NVG devices do not have the same qualities and response characteristics. Nevertheless, the discussion below is believed to relate to pilot NVG devices developed from GEN II^{plus} and Gen III tubes.

6.4.2 Color of Light

Blue green lighting is preferred because the minus-blue filter filters out the associated light wavelengths, thus not adversely impacting the NVG's, while at the same time the displays, surfaces, and switches illuminated with this light can be seen below or to the side of the goggles with the unaided eye. Certain white lights may prove non-intrusive in civil applications depending upon cockpit design and lighting configuration.

6.4.3 Location of Lights

Military experience has shown that, while not the preferred method, it is possible to use filtered floodlights to light the cockpit for NVG aided operations. [NOTE: The experience gained during early operations with full faceplate NVG configurations does not apply to this situation]. The larger the cockpit however, the more difficult it becomes to provide adequate lighting with floodlights alone. The use of filtered floodlights, if operationally acceptable, is the easiest and probably least expensive adaptation for the MD-500/BH-206 class helicopters. These can be located up under the sun-screen and/or over the pilot's shoulder. Shadows can be eliminated through the application of post lights, eyebrow lights, and/or multiple floodlights (see figure 9).

6.4.4 Redundant Sources

Floods, eyebrow, post, and integral lighting can provide redundant light sources.

6.5 COMPATIBLE COCKPIT SURFACES

6.5.1 Paint

The cockpit should be painted so as to minimize the potential for NVG detectable reflections, either directly on the wind screen or on the side windows (because civil aircraft are most often painted in light reflective colors, cockpit modification may be required).

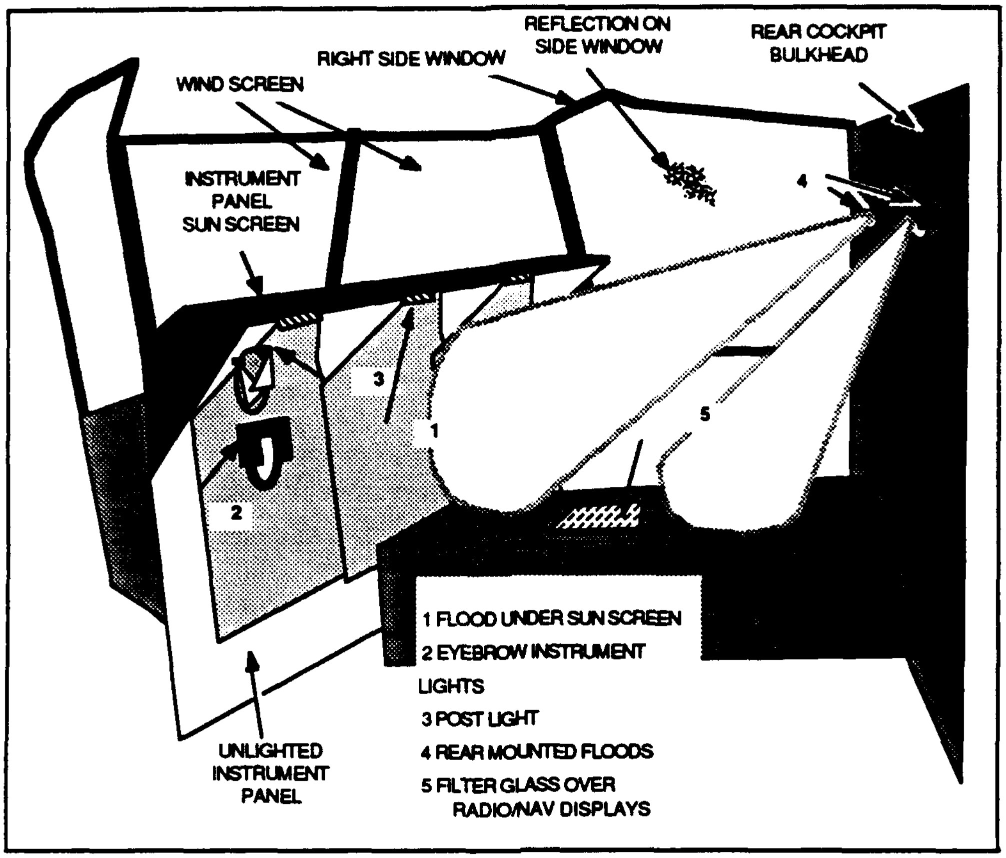


FIGURE 9 NVG COMPATIBLE COCKPIT LIGHTING

6.5.2 Cards and Placards

There are also light colored information cards and placards, sometimes lighted, which are very efficient, and therefore NVG intrusive. These tend to be sources of bright light which interfere with the operation of the NVG's because of the automatic gain control circuit (of the NVG's) and/or produce adverse visible reflections on the windscreen.

6.5.3 Clothing

White or light colored shirts and orange flight suits are examples of clothing which can cause reflections in the windows and windscreen, depending on eye to reflective surface angles and/or the type and intensity of the cockpit lighting.

6.6 CAUTION, ADVISORY, AND WARNING LIGHTS

6.6.1 General

Current conventional lighting incorporates green, yellow, amber, and red lights in the cockpit. Red light is particularly offensive to NVG operations. In the civil application however, that may not be cause for concern. It may be desirable, for example, to have the NVG's detect the red light from an emergency engine shut-down handle as long as the detection/reaction process poses no difficulty in the transition to unaided operations.

6.6.2 Altered Versus Unaltered Warning Lights

The location, color, and intensity of the warning lights and their impact on the type of NVG's which are to be used must be evaluated to determine the suitability of a given cockpit for NVG use.

6.6.3 Pilot Procedures

The pilot must have a preplanned response to caution or warning lights. The suitability of altered or unaltered warning lights is assumed to be tied to the procedure the pilot would follow after light illumination. It is expected that pilots will follow the same procedures and logic suitable for unaided operations.

6.6.4 Other Lights

Aircraft radios, navigation equipment control heads, weather radar, mission computers, and other equipments each have their own displays and varying types of internal and external lighting. These displays may or may not be compatible with NVG devices. Covers can be developed to either completely eliminate the light emitted from these displays or in some cases blue-green filter material may be installed to preclude interference of the displays. Additionally, cabin lights in use to support passenger/patient needs must be compatible, or the cabin must be isolatable, to prevent NVG operational degradation.

7.0 ILLUMINATION IN THE CIVIL ENVIRONMENT

7.1 INTRODUCTION

External light is that light which emanates from any source outside the cockpit. Such light can have as its origin any number of natural and man-made sources. The frequency and intensity of this light is of primary importance in evaluating its value/hinderance to a pilot conducting aided or unaided flight operations.

Some light is useful as an illumination source for NVG operations and can at the same time be used by the pilot for unaided operations. Others are of insufficient brightness to be detected by the unaided pilot but are still of considerable value when NVG's are used. In some cases, even though sufficient light is available, the reflectance from the object of interest is too low to be useful when viewed by the unaided pilot from a lighted cockpit. Whether aided or unaided, the issue is contrast. The greater the contrast, the more easily detectable and identifiable an object or surface will be. And finally, there is the basic question of each individual's ability to see in the night. Some pilots are more night adaptable than others. Some will detect objects at a given luminance that others will not.

The pilot of the aircraft shown in figure 10 is able to clearly see the butte in the foreground because the mountain in the background reflects the light from the moon. Short shadows enhance contrast and thus the definition of terrain. The mountain ridge line is silhouetted by the moon at high moon angles. This provides a strong horizon line for night visual flight. The size and location of the butte relative to the mountain provides the pilot with information which aids in the determination of relative height, closure rate, and relative distance between the two.

When the route of the flight takes the aircraft into the shadow of the mountain, the shadow defines an area or volume which is subject to relative low light levels. The adequacy of the remaining illumination will depend upon a number of factors. Nevertheless, operations within the shadow should be treated as potentially hazardous during both aided and unaided operations. If a pilot elects to fly into the shadowed area, as depicted in figure 11, he/she may eventually see the butte, but there is a strong possibility that the aircraft's speed will cause the aircraft to close on the butte so quickly that he/she may be unable to avoid it. This could happen with or without NVG's.

With NVG's the pilot will be able to see the obstruction sooner than without, but if the speed is too high the result may be the same. This problem can be avoided by avoiding flight into deep shadows. When flying in deep shadows is unavoidable, the pilot should reduce speed to some prudent ground speed and direct a searchlight along the flight path (figure 12). GEN III devices will provide better results than GEN II, but neither will be effective when used at excessively high speed or with poor pilot technique.

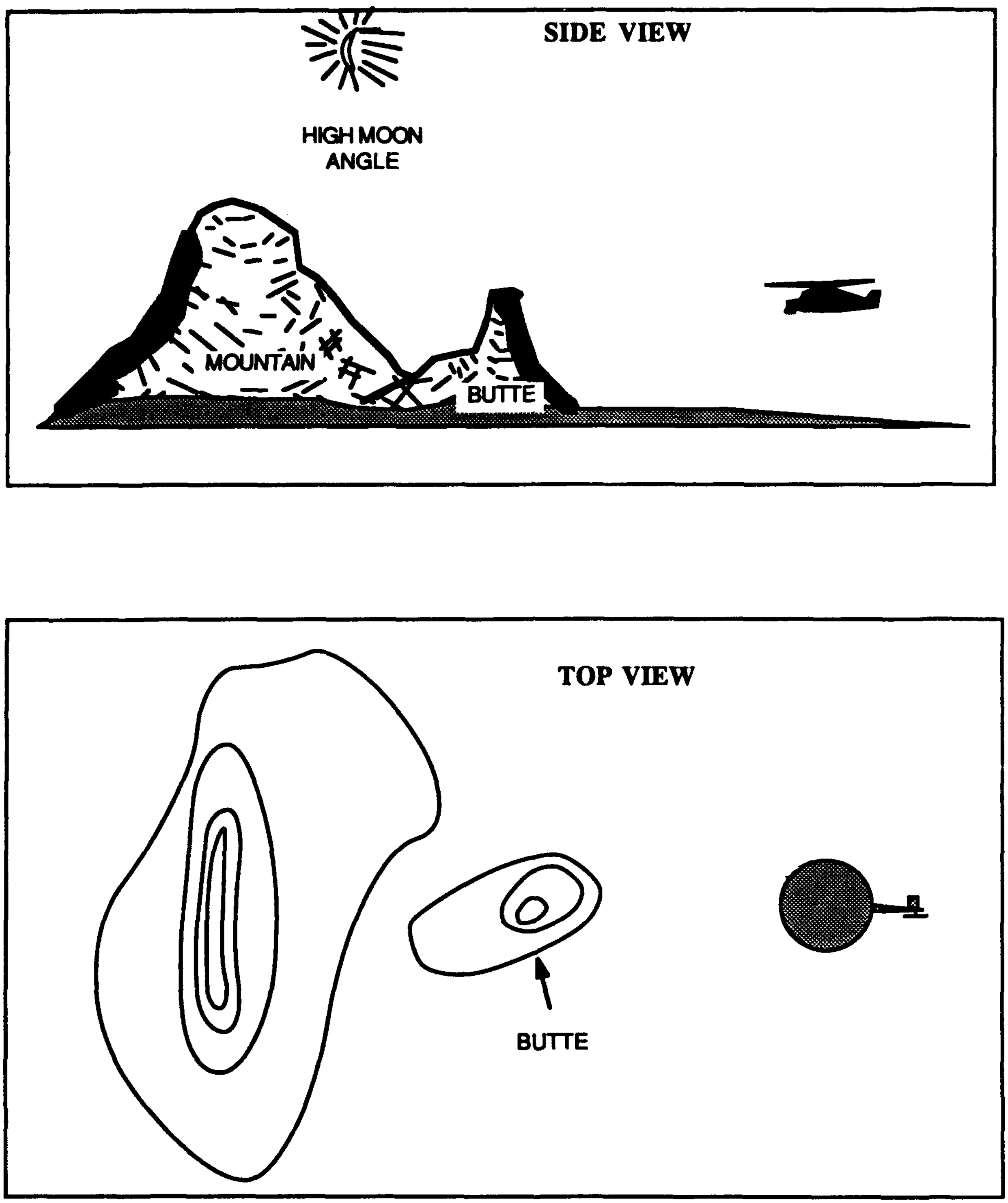
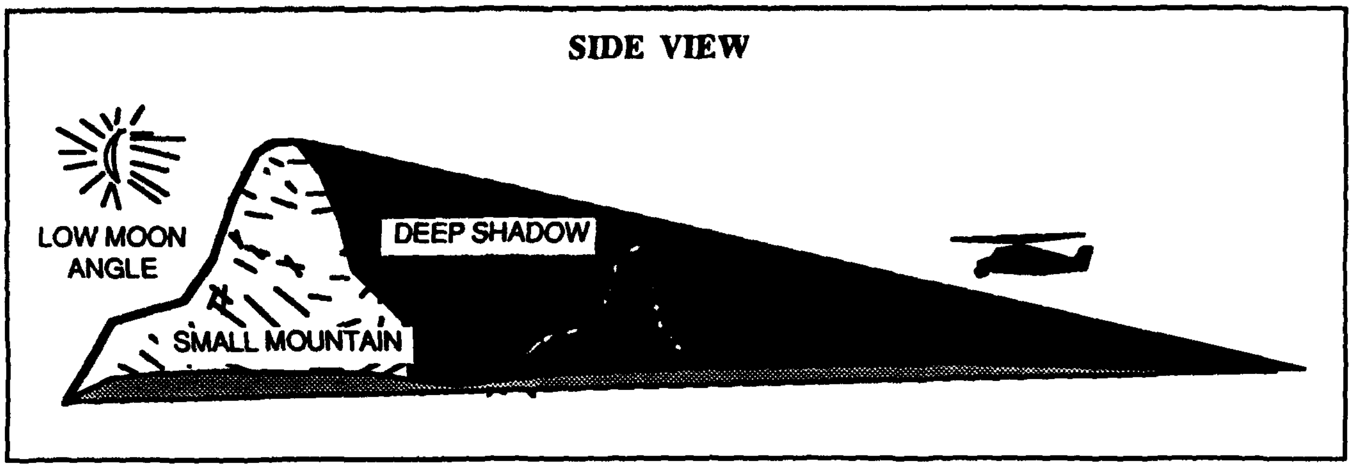


FIGURE 10 PILOT CAN SEE BUTTE BACK LIGHTED BY MOUNTAIN



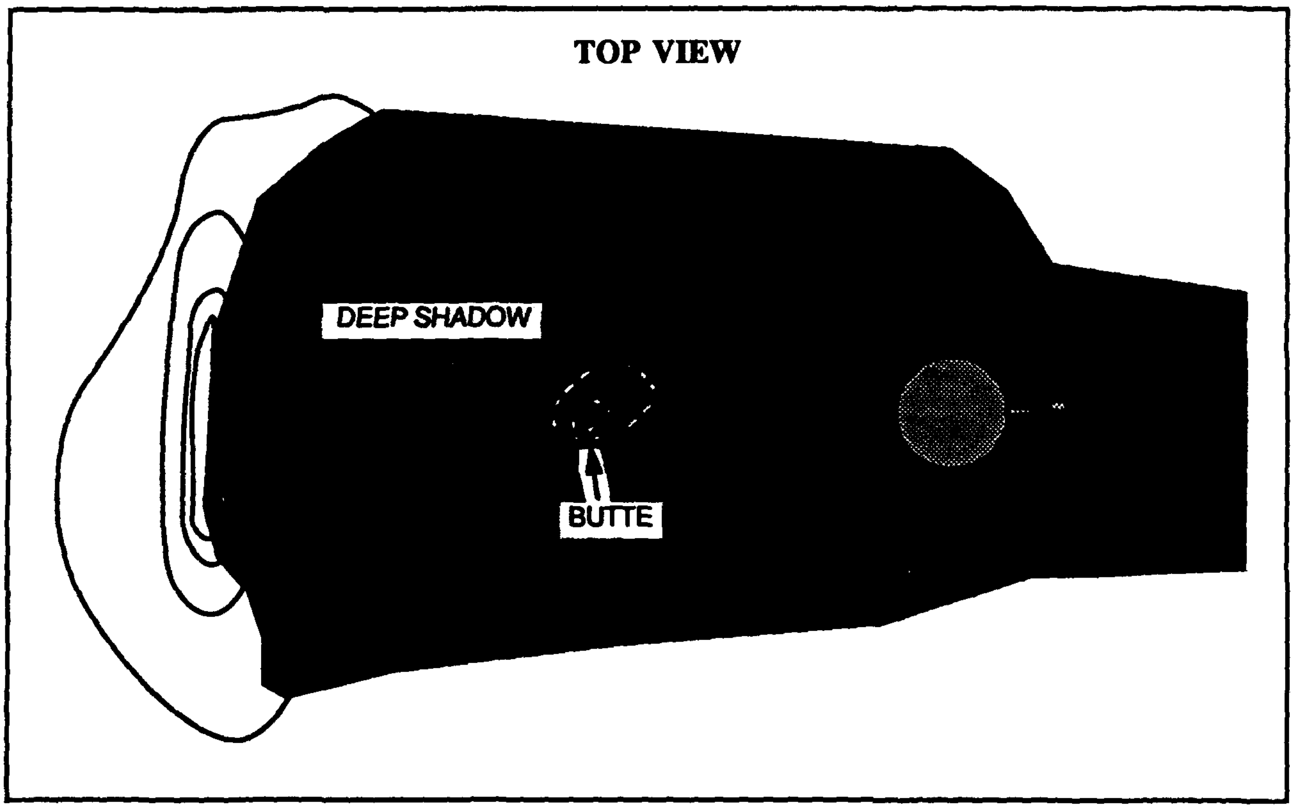
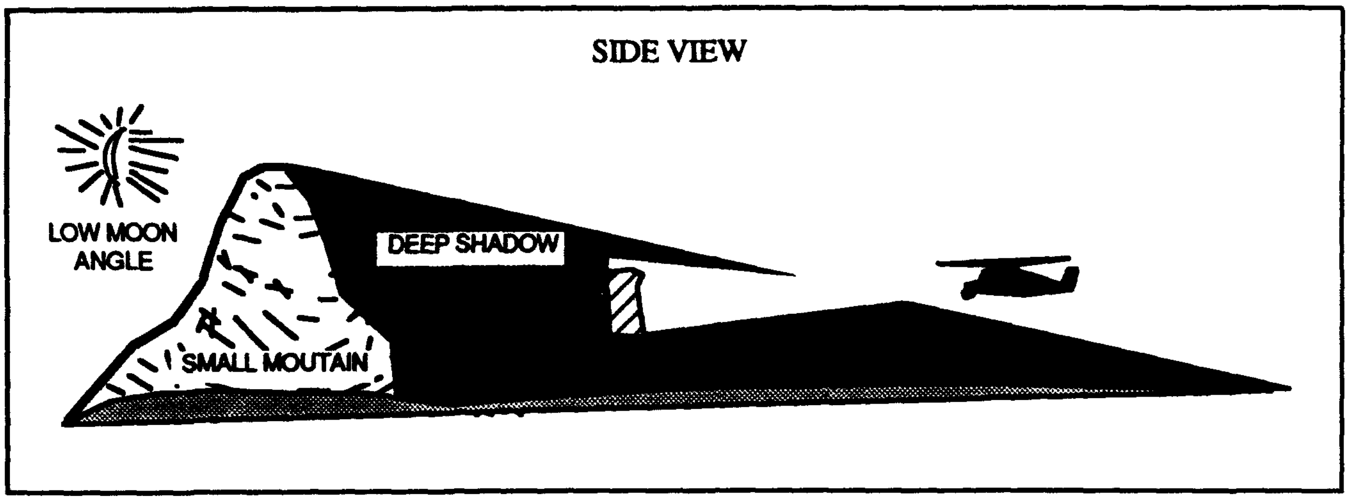


FIGURE 11 BUTTE IS LOST IN DEEP SHADOW



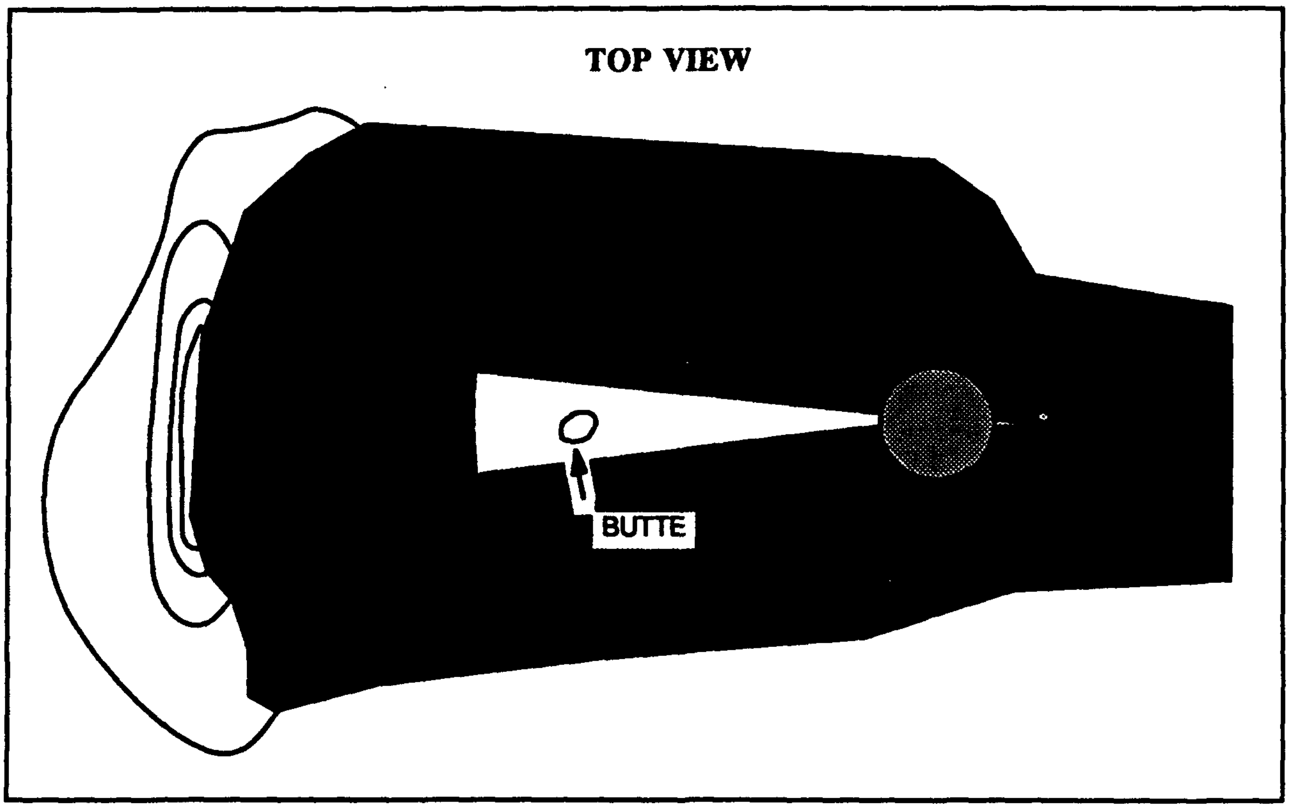


FIGURE 12 SEARCHLIGHT AIDS VISION IN DEEP SHADOW

When the moon rises above the horizon, it becomes a very strong source of illumination which, when viewed directly, can cause the NVG's automatic gain control circuit to reduce system gain. Depending upon the relative luminance received from terrain features and obstructions, their associated images can be overpowered or "washed out" by the overpowering bright light (figure 13).

The problem can be avoided by selecting headings which allow the pilot to see along the flight path without looking directly into the moon as shown in figure 14. If necessary, headings can alternate back and forth across the moon line. This condition exists for a relatively short period on any given night.

Ideally, lighting for normal NVG flight operations is at least 23 percent moon illumination at a minimum of 30 degrees above the horizon. The best view of the terrain occurs when the moon is above or over the shoulder of the pilot (see figure 15). Clear starlight provides sufficient light for GEN III operations, including military use for approaches to a hover and landing (see figure 16).

Depending upon the illumination source and the density/depth of the overcast, the frequency of the light visible to the NVG is in some cases capable of passing through the clouds (see figure 17). This ability to operate under an overcast has been discovered through experience. This characteristic, while known, is not well understood when it comes to approving/disapproving operations under an overcast. In certain military situations however, the ability to observe a clearly defined horizon has been the determining factor for an acceptable NVG operational situation.

The lights from a city many miles away will often reflect from clouds and provide usable local illumination. This light which reflects back to the surface, provides back lighting for terrain and other obstructions (see figure 18). While little has been written about this type of cloud reflective lighting, it is a common phenomenon which all aviators have experienced. There does not appear to be any documentation which quantifies this type of lighting in terms of adequacy for meeting military NVG minimum light requirements. Again, a useful rule-of-thumb has been developed to determine if sufficient illumination is available. An evaluation of the available light is made during preflight by proceeding to a suitable observation point and viewing the horizon through the NVG's. If there is a solid horizon line in the intended direction(s) of flight, the combined light from all sources is considered adequate.

It is also possible for NVG's to create a false sense of security by appearing to operate satisfactorily in a fog condition which would otherwise provide insufficient light for unaided vision. Upon entering an obscuration, and as the obscuration becomes thicker, the pilot will observe more and more electronic noise and a haloing or blooming of light sources; indicating that the ability to differentiate objects is decreasing and action should be taken to

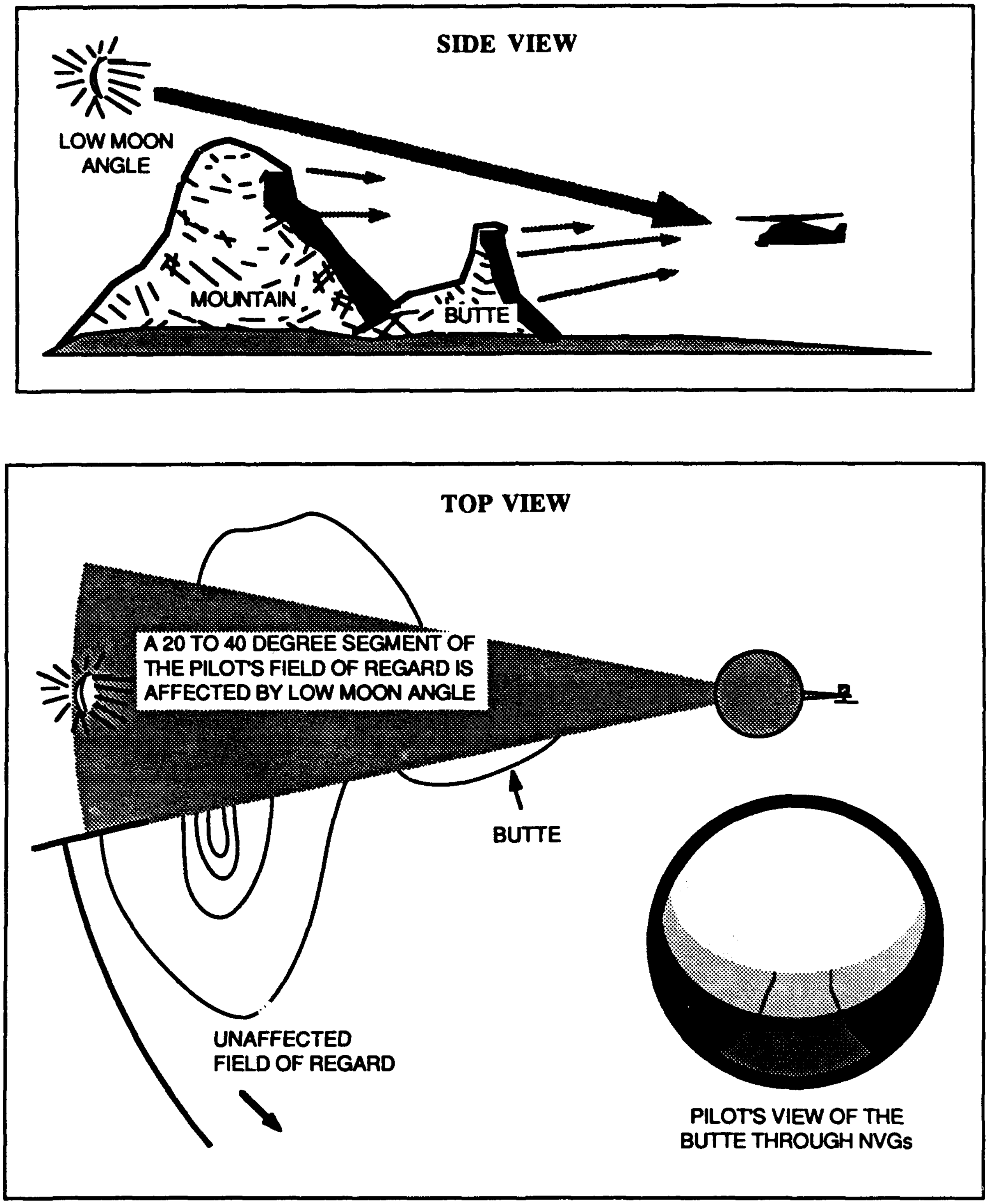
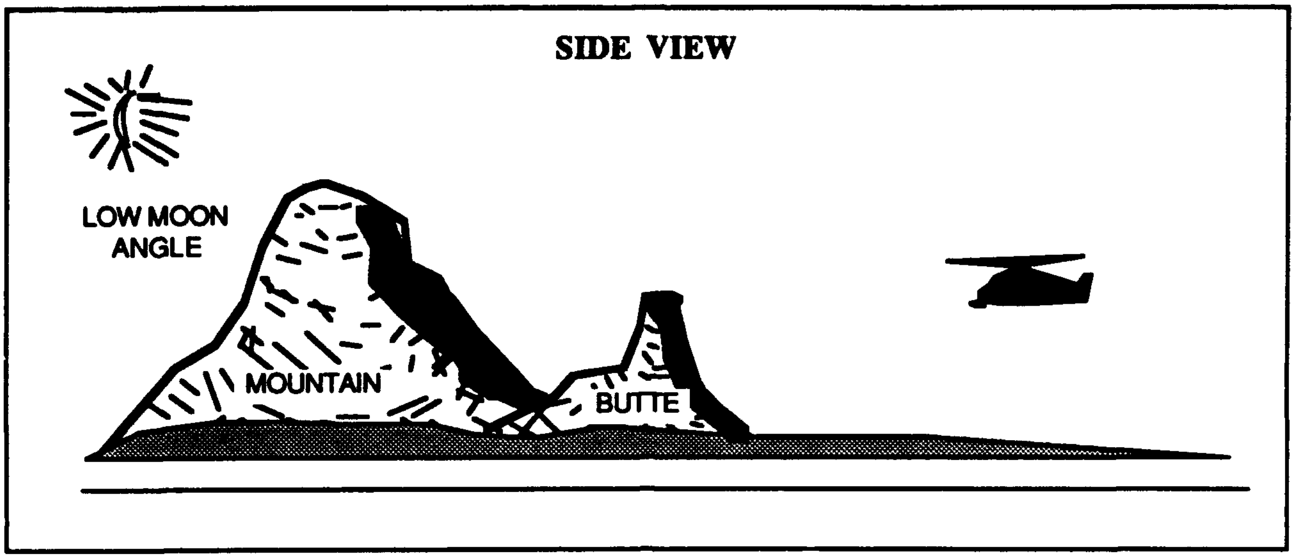


FIGURE 13 FLYING INTO LOW MOON ANGLES DECREASES THE DETECTABILITY OF OBSTRUCTION



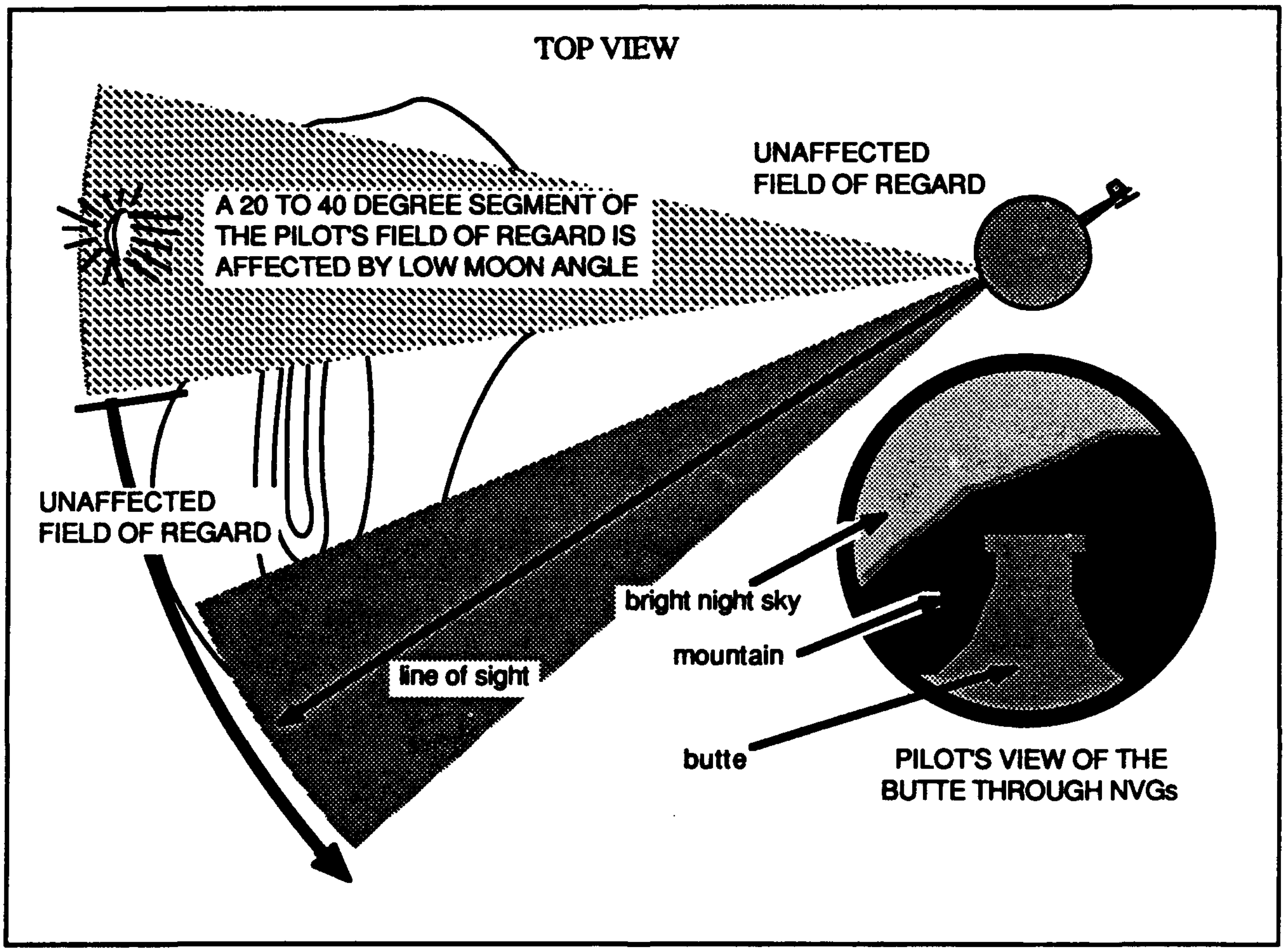


FIGURE 14 AVOIDING FLIGHT DIRECTLY INTO A LOW MOON WILL ENHANCE THE PILOT'S ABILITY TO DETECT OBSTRUCTIONS

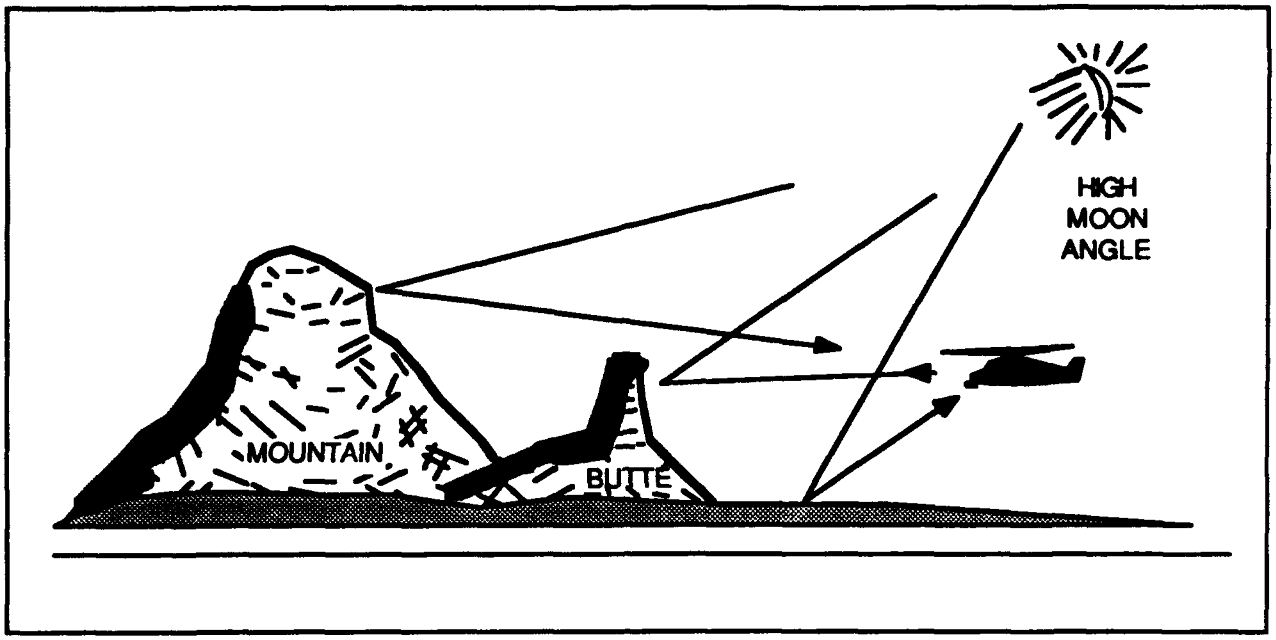


FIGURE 15 THE BEST LIGHTING COMES FROM A HIGH MOON OVER THE PILOT'S SHOULDER

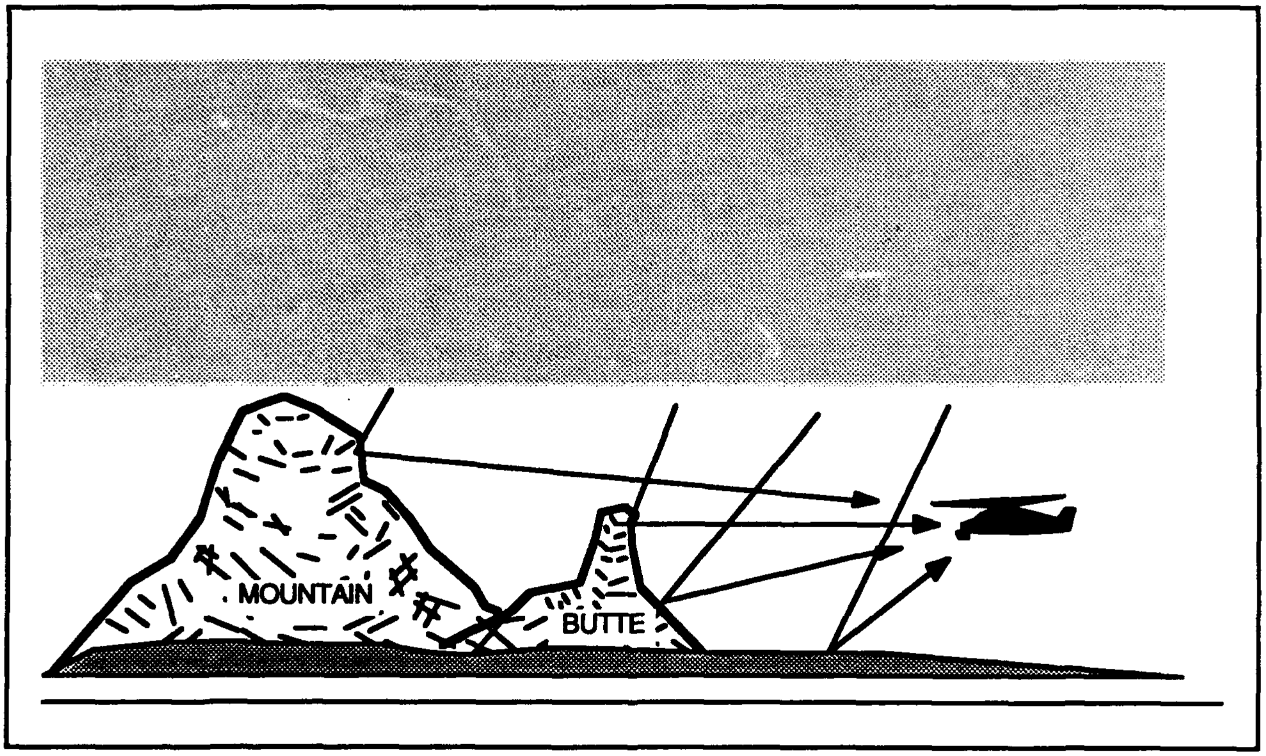


FIGURE 16 A CLEAR STARLIGHT SKY DEFINES THE MINIMUM NATURAL LIGHT FOR SAFE OPERATIONS NEAR THE GROUND

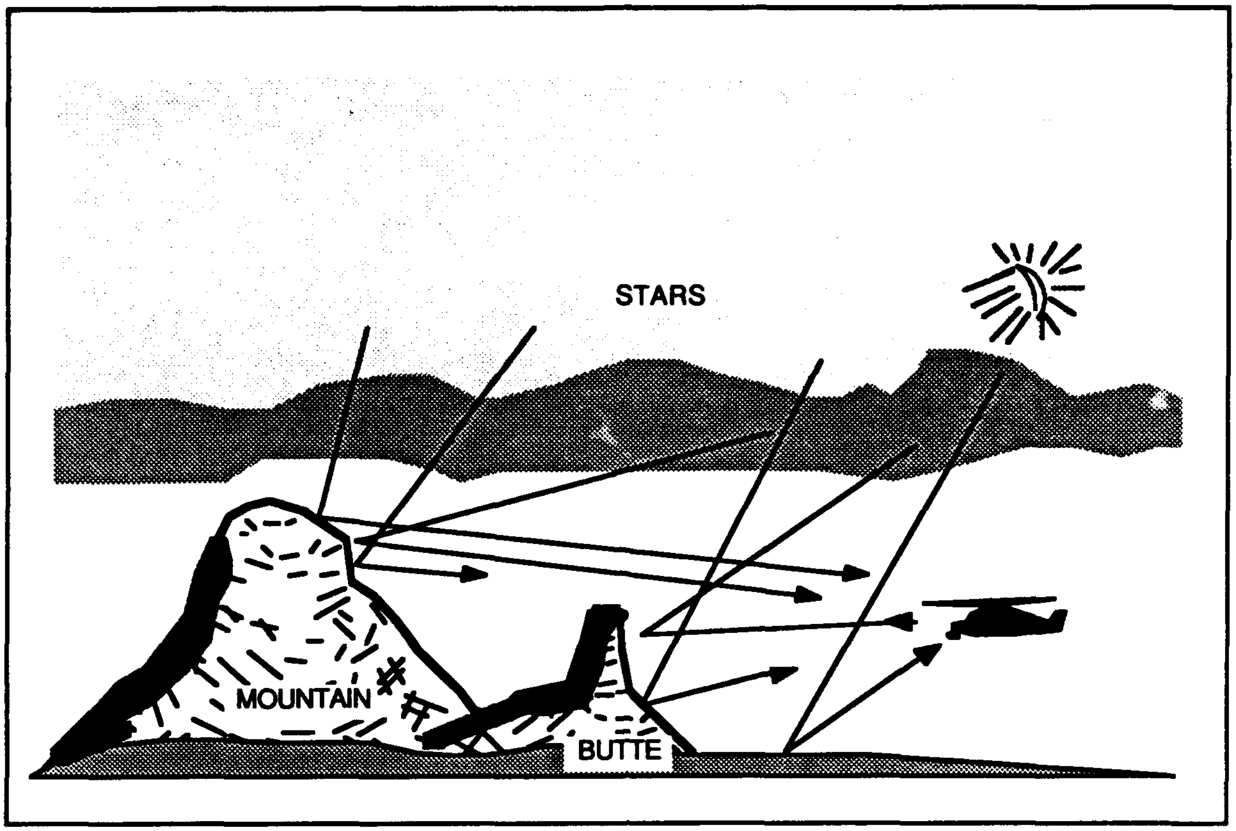


FIGURE 17 IT IS POSSIBLE FOR ADEQUATE LEVELS OF ILLUMINATION TO EXIST EVEN WITH AN OVERCAST CLOUD CONDITION

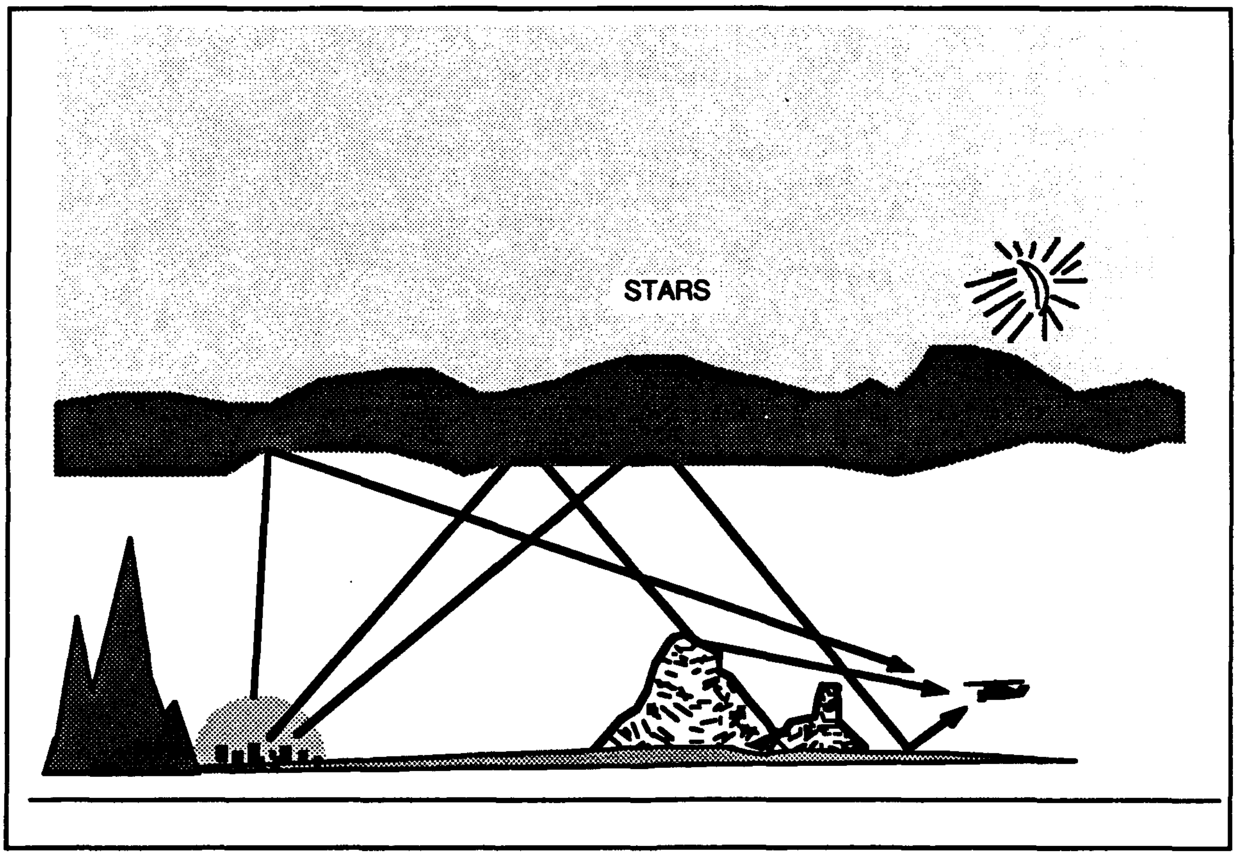


FIGURE 18 ILLUMINATION CAN COME FROM TOWNS AND CITIES MANY MILES AWAY ON CLEAR AND OVERCAST NIGHTS

improve the lighting situation (see figure 19). With proper training the pilot will learn to recognize these conditions early on to assure maintaining unaided visual contact with references on the surface (preferably out ahead on the intended route). NVG's give a marginal visual enhancement in heavy rain and have almost no utility in heavy falling snow.

It is possible to see power lines at night with total clarity using NVG's, only to have them disappear seconds later. The dimensions of the reflecting surface, the character of the reflecting surface, the reflectance of the surrounding terrain, the intensity of the light source, and the occluded angle all impact the pilot's ability to see particular objects, especially round surfaces like wires or poles with NVG's (see figure 20).

While it can be difficult to see certain types of objects such as poles and wires, aircraft navigation lights, obstruction lights and certain emergency ground vehicle lights can be seen and identified at dramatically greater ranges than is possible with the unaided eye (figure 21). This is especially true of red lights which lie in the NVG's most sensitive light spectrum.

Snow reflects a great deal of light and provides the best background in terms of reflected light. However, crews must be careful to fly above all obstructions or ensure that the speed of the aircraft allows the pilot to maneuver to avoid obstructions not visible because of excessive reflection. Figure 22 illustrates how a high peak does not become visible until the pilot passes over the snow covered bluff due to the high reflectance of the bluff.

7.2 HELICOPTER EXTERNAL LIGHTING

As a minimum, helicopters certificated to operate at night are required to have position lights and an anti-collision light. If operated for hire, a landing light is also required. The position lights typically have a bright and a dim setting which can be selected by the pilot in flight. The dim intensity of the position lights can be useful as a reflected light source during post take off and pre-landing operations at low altitudes. The anti-collision light need not be illuminated when the pilot determines that, because of operating conditions, it would be in the interest of safety to turn it off. It is uncertain how this provision applies to NVG operations.

7.2.1 The Fixed Landing Light

The fixed landing light is normally a flush mounted light on large helicopters and most modern smaller models. Some are externally mounted while others deploy from a flush mounted position to a single fixed position. Many pilots fly at night with the landing light deployed in order to be prepared for an emergency landing (autorotation). These single landing lights tend to be narrow beamed lights designed for aiding the pilot during approach and landing. As

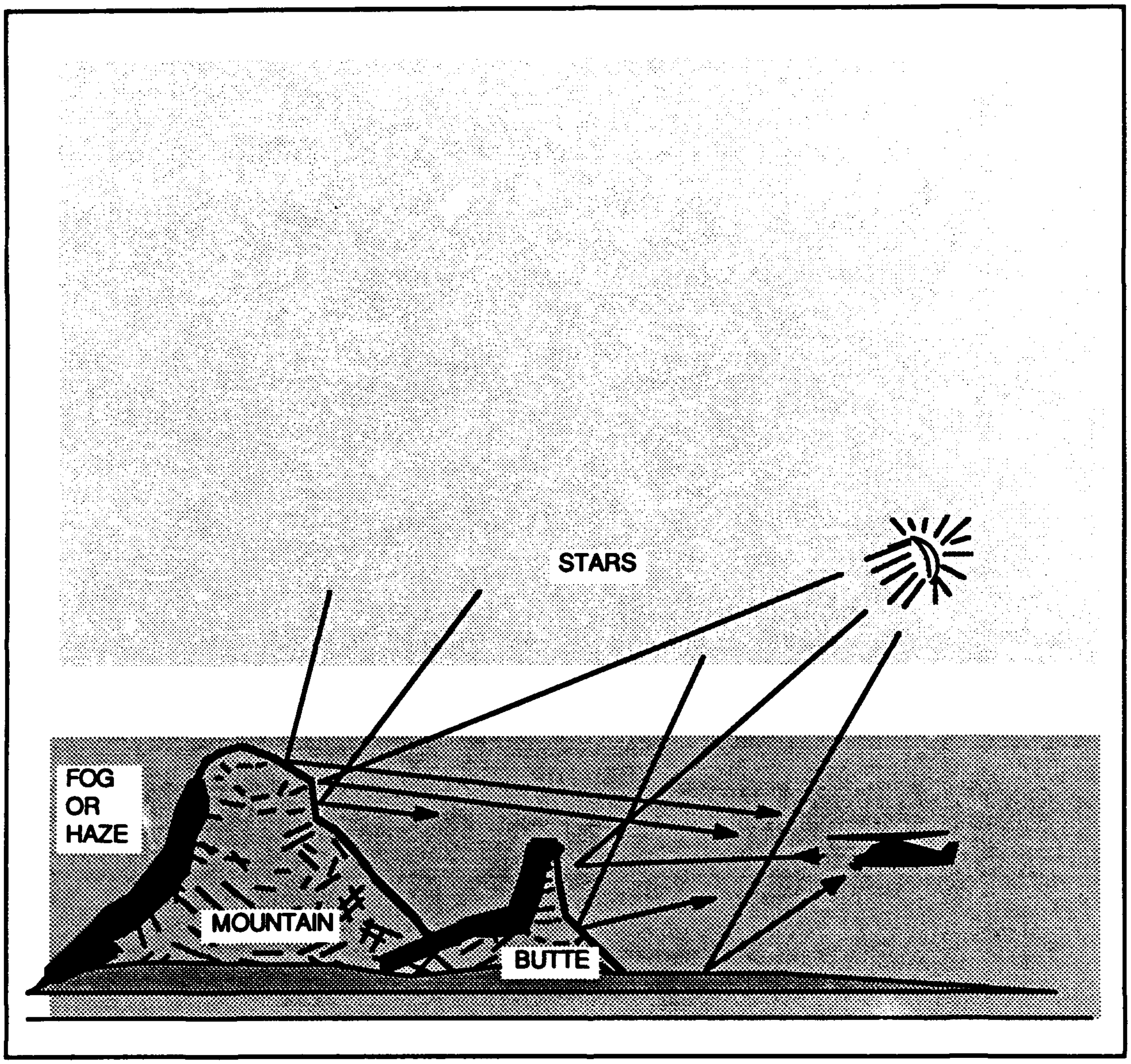


FIGURE 19 IT IS POSSIBLE FOR ADEQUATE LEVELS OF ILLUMINATION TO EXIST WHEN OPERATING IN THIN FOG OR HAZE OBSCURATION

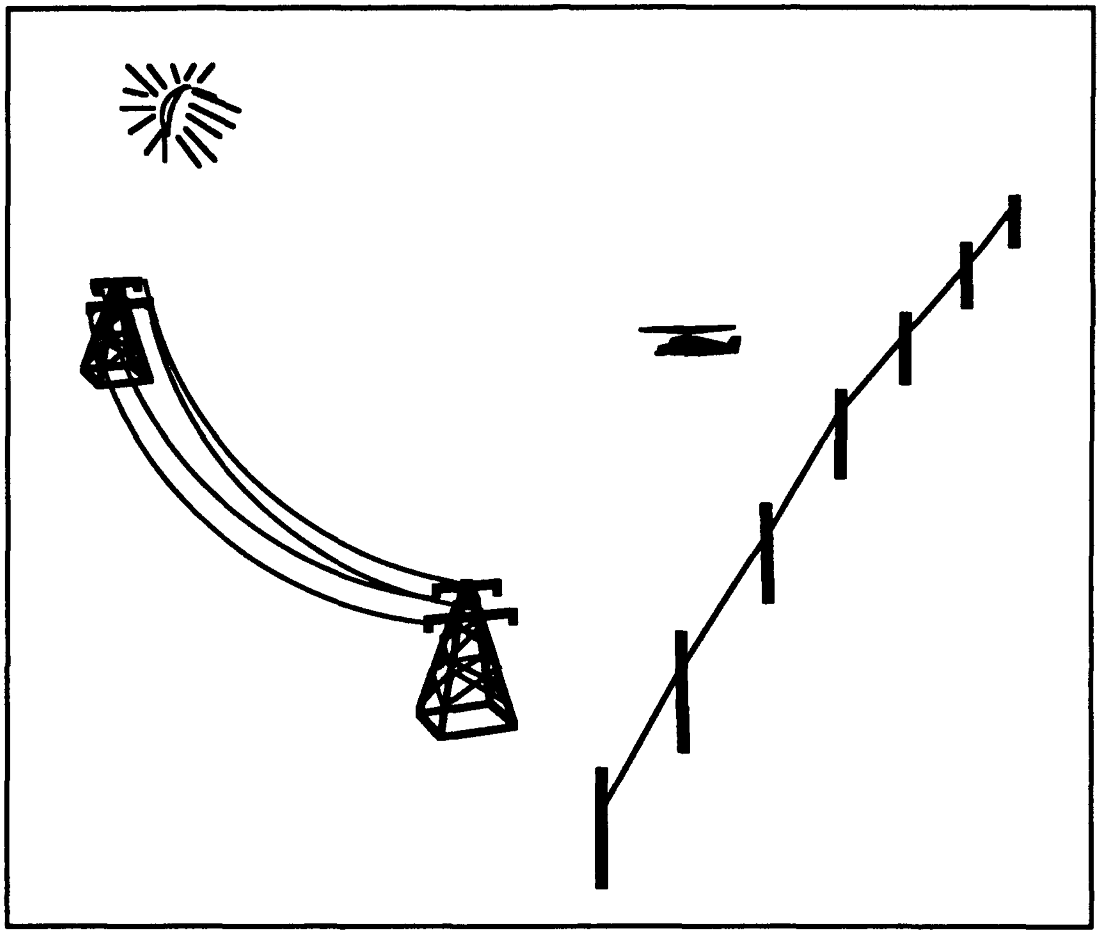


FIGURE 20 WIRES MOST LIKELY CAN NOT BE SEEN BECAUSE THE ANGLE BETWEEN THE PILOT'S EYES AND THE SOURCE IS TOO GREAT

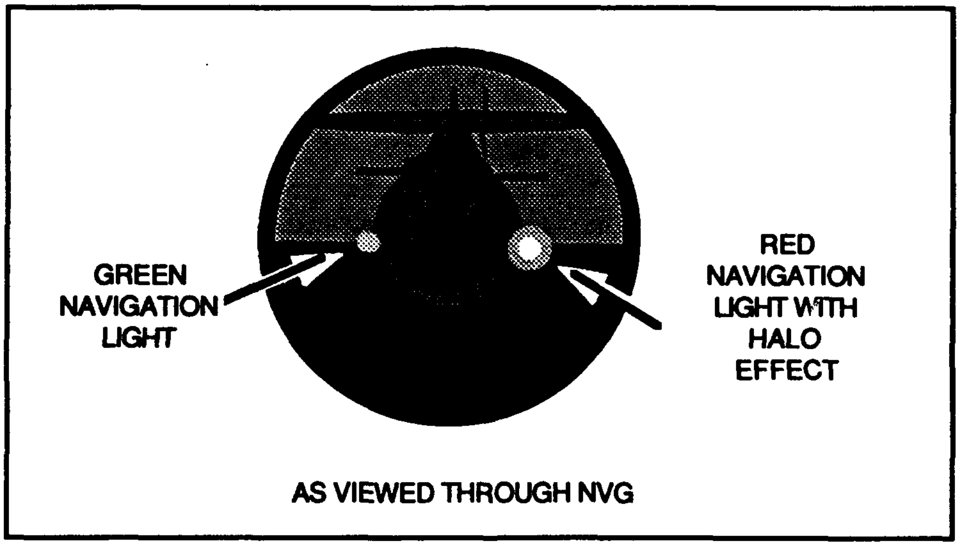
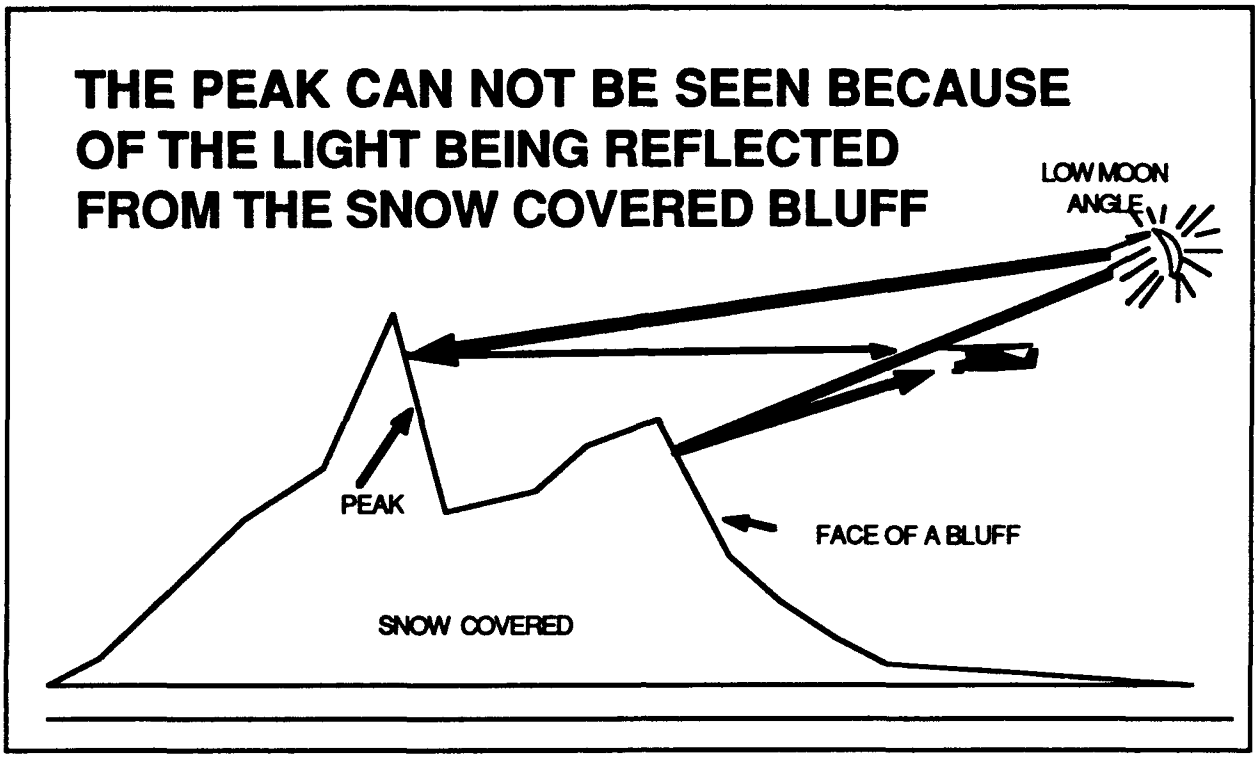


FIGURE 21 SOME LIGHTS APPEAR TO BE CLOSER THAN THEY ARE BECAUSE OF INTENSITY OR COLOR



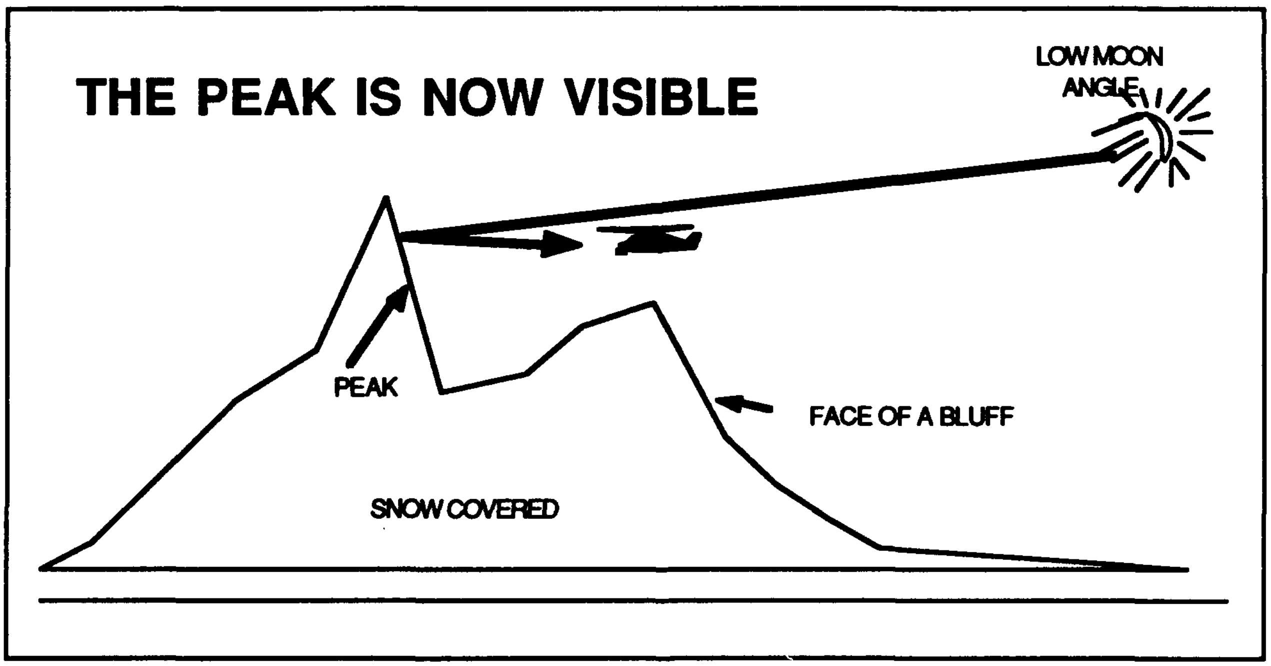


FIGURE 22 THE PEAK CAN ONLY BE SEEN AFTER PASSING THE LOWER BLUFF BECAUSE OF THE EXCESSIVE LIGHT BEING REFLECTED FROM THE FIRST SNOW COVERED BLUFF

the aircraft approaches the surface, these beams produce a very small spot of light which often disappears under the nose and out of view as the aircraft descends to hover height. The illumination characteristics of such lights do not provide the pilot with much capability to clear the aircraft laterally.

7.2.2 Controllable Spot/Searchlights

The larger, more expensive helicopters, and those helicopters which are routinely operated into and out of modestly improved or unimproved sites, often add a pilot controllable spotlight. This device allows pilots to more thoroughly evaluate a specific landing site and its associated approach and departure paths. It may also be used to find and identify objects and landmarks on the ground.

7.2.3 Floodlights

It is not uncommon for helicopters to be equipped with one or more fixed floodlights which are arranged in a way that will allow the crew to brightly illuminate the entire landing area. As many as six additional floods were observed on operational aircraft during this evaluation.

7.2.4 IR Flood/Spotlights

Some argue that IR filter glass should be placed over the flood and spotlights to enhance the ability of pilots to use them during NVG operations at night during low ambient light levels. The Army uses such lights as back-up, safety lights for NOE operations. Because there is no civil prohibition to the use of normal lighting, the usefulness of such filters is uncertain.

7.2.5 Intense Blue-Green Flood/Spotlights

Blue-green light is visible to the unaided eye while at the same time filtered by certain goggles. The use of such lighting may offer the pilot the ability to view the near surface unaided while at the same time gaining the benefit of the far field use of the NVG's.

7.2.6 Unaided Night Vision

There may be concern about the impact of white and/or blue-green internal and external lights on pilot night vision. While this study does not dispel such concerns, neither does it identify any particular reason for such concern.

8.0 ANALYSIS OF CIVIL OPERATOR OBJECTIVES

8.1 INTRODUCTION

This section summarizes the observed and postulated civil operator objectives which could be determined within the scope of this study.

8.1.1 Findings

There are two modes of flight which are significant to civil rotorcraft operations:

(1) en route operations, and
(2) terminal area operations (approach, hover, landing, takeoff, departure).

There are two interface situations of prime importance:

(1) pilot-NVG to the outside world, and
(2) pilot-NVG to inside the cockpit.

The transition to/from NVG operations requires that the FAA evaluate the need for additional special operating considerations.

Pilot workload, stress, and situational awareness are substantially improved using NVG's during en route and pre-landing maneuvering, especially at unfamiliar sites. NVG's can also be used to ensure accurate navigation, to aid in obstruction avoidance, and to minimize the tendency for spatial disorientation.

8.1.2 Considerations

Factors that must be considered in a variety of scenarios include:

- o internal and external lighting requirements;
- o aided versus unaided field of view:
  - (1) cockpit situation,
  - (2) air traffic awareness,
  - (3) terrain, and
  - (4) inspection of unfamiliar terrain.

8.2 ALTERNATE AIDED-UNAIDED VIEWING

While requiring further evaluation, the ability of a single crewmember to alternately view the terrain using NVG aided and unaided viewing techniques appears superior to the use of unaided viewing and conventional lighting techniques alone.

8.2.1 Factors to Consider

The pilot must alternately look around and through the eyepiece to detect features which are more prominent via each technique. This is not unlike the complementary characteristics of forward looking infrared (FLIR) and low light level television (LLLTV). The need to scan thru and around the NVG device appears to be easily achievable without requiring undue pilot skill.

8.2.2 Unaided Viewing of Cockpit/Unaided Field of View

The pilot has the ability to look to the right, left, and under the NVG's for an unaided view of points of interest both inside and outside of the cockpit.

8.2.3 Work Tasks

Work tasks were evaluated as a part of the analysis of planned profiles and modes of operation. None appeared to require any unusual pilot skill.

8.3 OPERATIONS

It would appear that there is no current or pending civil operator requirement to conduct an approach to a hover/landing on NVG's alone. Should there be such a requirement, the consideration of comparative risk appears treatable on a case by case basis. The most significant argument for NVG aided hover/takeoff operations might involve operations from unprepared sites under visual conditions which are made difficult by the absence of distinct surface definition immediately after take-off. The approach to landing scenario appears to be more realistically accomplished via conversion to conventional approach/hover lighting.

8.3.1 Conversion

Conversion addresses the transition from conventional lighting/ visualization techniques to NVG aided operation. The following considerations apply to conversion:

- o NVG's are properly preflighted and mounted prior to takeoff,
- o pilot can quickly and accurately position NVG's for primary viewing,
- o pilot can quickly displace NVG's from primary viewing position and return to conventional operations, and
- o cockpit is compatible with aided and unaided operations (reflective surfaces, lighting, etc.):
  - for viewing outside the helicopter - unaided
  - for viewing inside the cockpit (instruments) - unaided
  - for viewing through NVG's.

8.3.2 Reconversion

Reconversion refers to the transition from NVG aided flight back to unaided flight. The following considerations apply to reconversion:

- o NVG's must be mounted so as to be easily displaced during the transition,
- o night adaptation must not be noticeably degraded,
- o transition must be no more demanding than the transition from instrument flight, and
- o cockpit lighting requirements using NVG's must not be incompatible with the transition to unaided flight.

8.4 OPERATING RULES/OPERATIONS SPECIFICATIONS

8.4.1 Part 91

Under Part 91 there is neither prohibition nor guidance provided regarding the use of night vision devices. Other than defending oneself against an allegation of carelessness and recklessness, it would appear that any attempt to acquire proper training and the application of prudent judgment in their use would prevail given the lack of guidance provided.

8.4.2 Part 135

While the same level of prohibition or guidance from Part 91 applies in the case of the Part 135 operator, scrutiny of their operating practices is much greater and the carrying of passengers for hire more regulated. Assuming that proper training were provided, the following paragraphs describe some possibilities/considerations for Part 135 operations.

8.4.2.1 Single Pilot With Passengers

A typical civil NVG operation is envisioned as follows: conventional departure, followed by conversion to NVG's, followed by reconversion at some initial approach point within the normal conventional approach capability of the crew and aircraft. This defines en route use of NVG's as an aid to night operations.

8.4.2.2 Dual Pilot and/or Additional NVG Trained Crewmembers With Passengers

Operational circumstances under which two NVG qualified pilots and/or additional trained crewmembers would be desired/required remains unresolved. When public service operations (drug interdiction, law enforcement, surveillance, etc) wish to operate undetected (lights out), the second or third aided crewmember acting as an observer(s) may be required. In consideration of current public service use it would appear that advisory materials covering this issue are urgently needed as guidance for proper NVG use and to cover possible future civil applications.

9.0 CONCLUSIONS

The following conclusions were arrived at during the course of this investigation. They are based upon the collective best judgments of the principal investigators involved and the inputs of numerous night vision device technical and operational experts.

9.1 NVG USE IN THE CIVIL APPLICATION

The civil use of NVG's as an aid during en route and certain terminal operations (climb out, landing area surveillance, approach path selection, etc.) can increase safety, enhance situational awareness, and significantly reduce the pilot workload/stress normally associated with night flying.

9.2 SINGLE PILOT OPERATORS

Any evaluation must recognize that many of the operators using NVG's are currently single piloted. The evaluation must consider the differences in the night flying tasks of the single piloted operators as compared to the dual piloted operators.

9.3 PUBLIC USE NEEDS

Guidance in the development of required training and proper use of night vision devices is urgently needed to support their use by public service operators who operate with them today in the civil portion of the national airspace system.

9.4 COCKPIT COMPATIBILITY

Cockpit compatibility encompasses a significant number of issues which must be resolved prior to full implementation. These issues include: light sources, light intensity, light color, paint color, windscreen design, acceptable clothing, instrument placement, cockpit/cabin isolation, etc,. Because of the subjective nature of any resolution of these issues, training must be provided to principle operations inspectors (POI) regarding the requirement for, and effectiveness of, various modifications on night vision device performance.

9.5 GEN II VERSUS GEN III

There are significant differences in performance and cost between GEN II and GEN III devices. However, it is expected that operational need rather than cost will dictate equipment selection. Differences in performance will likely require different training.

9.6 CREW REST/FATIGUE

The fatigue and additional crew rest requirements associated with military NVG use are not thought applicable to the civil operation addressed in this report. This may not be the case for the public service operator and therefore should be investigated.

9.7 FLIP-UP VERSUS LOOK-UNDER

The option of looking out under the goggles versus flipping them up on the approach, while recommended to be left to pilot preference, may not be feasible for pilots who wear bi-focal corrective lenses. This issue requires further analysis. No other applicable physiological or psychological issues were uncovered.

9.8 INSTRUMENT SKILLS

An NVG pilot needs good instrument skills to back up NVG flight.

9.9 NIGHT VISION RECOVERY

Normal night vision is degraded to some extent when wearing night vision goggles. Assessment must be made of the recovery time involved in reconversion and whether or not there is any operational/safety impact.

9.10 TRAINING

Proper training in the use of night vision devices is essential both to ensure operational safely and to maximize the benefits from their use. Some essential questions relative to training which must be addressed in follow-on analyses are:

- o who is or can be qualified/certified to provide essential training?

- o what must the training cover?
    - proper wear of night vision devices,
    - recognition of deteriorating weather,
    - terrain board use,
    - operation in low contrast environments,
    - equipment testing prior to use,
    - detection of deteriorating performance,
    - scanning discipline,
    - proper use of lights, internal and external,
    - recurrent training requirements, and
    - maintaining PROFICIENCY.

9.11 ELECTROMAGNETIC INTERFERENCE

The issue of electromagnetic interference must be investigated to ensure NVG compatibility with the electronic flight information/ digital flight information (EFIS/DFIS) systems in today's most modern aircraft.

9.12 MAINTENANCE

Maintenance responsibilities, equipment testing requirements, and procedures must be established for night vision devices.

10.0 RECOMMENDATIONS

The FAA has established a follow-on program to operationally evaluate civil NVG use. This program involves evaluation of training requirements, simulator evaluation of pilot performance during simulated mission scenarios, and actual flight test evaluation of pilot performance while using NVG's. During these evaluations, it is recommended that as many of the following issues as possible be addressed/resolved and that advisory/regulatory materials be developed as necessary to allow introduction of the use of night vision devices in civil applications.

10.1 SIMULATION

The following simulation actions should be undertaken:

- o evaluate acceptable cockpit lighting (type and placement, caution and warning lights effects, etc.),
- o evaluate single pilot operations (capabilities/limitations),
- o evaluate type and quantity of training required for night vision device qualification, and
- o evaluate type and quantity of recurrent (proficiency) training required.

10.2 FLIGHT EVALUATION

Recognizing that some aspects of flight evaluation require an aircraft but may not require flight (e.g., experimentations with lighting configurations, settings, placements, etc.), the following items should be evaluated during the flight evaluation program:

- o evaluate the value of/requirement for radar altimeter during en route/approach/landing;
- o evaluate cockpit lighting effects on NVG/pilot performance;
- o evaluate external lighting uses/effects on night vision goggle performance;
- o evaluate NVG pre-flight requirements for the pilot/equipment/aircraft;
- o evaluate pilot's ability to recognize impaired goggle performance (degrading/failure);
- o evaluate GEN II and GEN III performance differences; and
- o determine the crossover point (altitude) where external lights and unaided vision become more effective than goggles.

10.3 REGULATORY ISSUES

A number of regulatory issues arise covering a variety of topics. The following paragraphs contain recommendations concerning a number of those issues.

10.3.1 Qualification/Evaluation

To ensure proper training is received and proficiency maintained, it is recommended that the use of night vision devices be considered a separate rating to be listed on the pilot's certificate and that night vision device knowledge and use become part of the pilot's flight evaluation.

10.3.2 Installed Versus Personal Equipment

It is recommended that night vision devices be considered installed aircraft equipment. Doing so will require fewer sets of goggles (thus reducing cost) to support a given operation, while at the same time requiring better maintenance, monitoring, inspection, and record keeping.

10.3.3 Areas of Operation

It is recommended that operational use of night vision devices be based upon trained pilot judgement as to their effectiveness in each circumstance. Use in a terminal control area, control zone, airport radar surveillance area, terminal radar surveillance area, etc. should be based upon their benefit to the situation.

10.3.4 Flight and Duty Time

This study does not identify any requirement for the application of additional flight and duty time restrictions for civil NVG use beyond those required for current operations. This issue may need to be revisited as it applies to public service use of night vision equipment.

10.4 OFFSHORE USE OF NIGHT VISION DEVICES

During the course of the investigation both positive and negative reactions were given concerning the use of night vision devices over water. The provision of a clear horizon line could, however, outweigh all of the perceived drawbacks in an otherwise extremely difficult operating environment. It is therefore recommended that the FAA investigate offshore use of NVG's as part of their continuing efforts.

APPENDIX A
UNITS AND ACTIVITIES VISITED

Office of the Program Manager, Night Vision Electro Optics, Ft. Belvoir, VA, 28 August 1989

Attendees: John Gresham, Deputy Project Manager
Mack Farr, Technical Director
Dick Russell, HQ FAA, Commuter & Air Taxi Branch (AFS-250)
Bob Hawley, Systems Control Technology, Inc
David Green, Starmark Corporation
Joseph Rears, Starmark Corporation

Synopsis: Reviewed technical/performance issues concerning NVG's

Night Vision Laboratory, Ft. Belvoir, VA, 28 August 1989

Attendees: Captain Brian Gillespie
Kevin Mayes, Project Engineer
Dick Russell, HQ FAA/AFS-250
Bob Hawley, SCT
David Green, Starmark
Joseph Rears, Starmark

Synopsis: Addressed Army operations and training concerns

Rocky Mountain Helicopters, Knoxville, TN, 30 August 1989

Attendees: Dale Fowler, Chief Instructor Pilot
Bill Flannery, Instructor Pilot
Bob Hawley, SCT
David Green, Starmark
Joseph Rears, Starmark

Synoposis: NVG demonstration flight, reviewed proposed training plan

U.S. Army Safety Center, Ft. Rucker, AL, 11 September 1989

Attendees: LTC Bernie Wall
MAJ John S. Crowley MD, Aerospace Medicine
John Brown, HQ FAA Vertical Flight Program Office (ARD-30)
Bob Hawley, SCT
David Green, Starmark
Joseph Rears, Starmark
Clark Burnett, Consultant

Synoposis: Reviewed accidents, causes, lessons learned

Night Vision Systems, Aviation Training Brigade, Ft. Rucker, AL, 12 September 1989

Attendees: MW4 Robert Brooks
Bob Hawley, SCT
John Brown, HQ FAA/ARD-30
David Green, Starmark
Joseph Rears, Starmark
Clark Burnett, Consultant

Synoposis: Army Aviation NVG history and current training issues

Directorate of Evaluation and Standardization, Fort Rucker, AL, 12 September 1989

Attendees: Rick Barron, DAC Flight Instructor
John Brown, HQ FAA/ARD-30
Bob Hawley, SCT
David Green, Starmark
Joseph Rears, Starmark
Clark Burnett, Consultant

Synoposis: Training issues

20th SOF, Hurlburt Field, FL, 12 September 1989

Attendees: LTC Russell, USAF, Operations Officer
Bob Hawley, SCT

Synopsis: Training issues

Aviation Training Center, Mobile AL, 13 September 1989

Attendees: LT Steve Hickock, USCG
John Brown, HQ FAA/ARD-30
Bob Hawley, SCT
David Green, Starmark
Joseph Rears, Starmark

Synopsis: Terrain board and eyelane demonstration, training.

ITT Electro-Optical Products, Roanoke, VA, 20 September 1989

Attendees: Jim Eder, ITT
Norm Phillips, ITT
Robert Williams, ITT
Andy Decicco, ITT
Bill Mims, ITT
Joe Walker, Principal Operations Inspector (POI), FAA
Dale Fowler, Rocky Mountain Helicopters
Bill Flannery, Rocky Mountain Helicopters
Bob Hawley, SCT
John Brown, HQ FAA/ARD-30
David Green, Starmark
Joseph Rears, Starmark

Synopsis: Technical issues

Litton Electronic Devices, Tempe, AZ, 26 September 1989

Attendees: Gene Adcock, Litton
Roland Morley, Litton
Arnold Davis, Litton
Chuck Frisenhahn, HQ FAA, Flight Technical Programs (AFS-400)
John Brown, HQ FAA/ARD-30
Bob Hawley, SCT
David Green, Starmark
Joseph Rears, Starmark

Synopsis: Technical issues

McDonnell Douglas Helicopter Company, 26 September 1989

Attendees: George Ross, McDonnell Douglas
Al Calvert, McDonnell Douglas
Chuck Frisenhahn, HQ FAA/AFS-400
John Brown, HQ FAA/ARD-30
Bob Hawley, SCT
David Green, Starmark
Joseph Rears, Starmark

Synopsis: Demonstration flight, technical and training issues

APPENDIX B
OSD REVIEW OF TESTING

The following is reprinted from:

Review of Testing Performed on
AN/PVS-5 and AN/AVS-6
Aviation Night Vision Goggles
30 June 1989

Office of the Director
Operational Test and Evaluation
Secretary of Defense

for ready reference.

Adequacy of Testing

(1) AN/PVS-5

Numerous developmental and operational tests were performed on the AN/PVS-5 night vision goggles to determine their effectiveness as a night vision aid for pilots and other aircrew members (References 1-15, Appendix C).*

These tests began as early as 1971 with the Combat Air Vehicle Navigation and Vision Study conducted by the U.S. Army Land Warfare Laboratory at Aberdeen Proving Ground, Maryland. Positive recommendations from this test resulted in a decision to conduct a unit evaluation as part of the Modern Army Selected Systems Test, Evaluation and Review (MASSTER) at Ft. Hood, TX in late 1972. Over 700 hours were flown in an operational environment in three different helicopter types and included single helicopter operations, multi-helicopter formation flights and weapons firing. The report recommended immediate adoption of the AN/PVS-5 for ground and aviation use. Concurrently, but not as a part of the Army tests, the U.S. Air Force Military Airlift Command (MAC) evaluated the AN/PVS-5 with 40 degrees FOV in comparison to the SU-50 with 60 degrees FOV. Their report concluded that the AN/PVS-5 NVG was superior to the SU-50 NVG and would enhance night flight operations.

Developmental tests on the AN/PVS-5 NVG's were completed during 1972-75 and the U.S. Army Aeromedical Research Laboratory (USAARL) conducted a series of tests on the AN/PVS-5 NVG's that identified NVG performance shortcomings and evaluated modifications to the basic goggle between 1975-1986 (Reference 16, Appendix C).

The performance shortcomings identified during testing included:

(a) Marginal performance at light levels below 1/4 moon illumination (degraded imagery, loss of depth perception and visual noise, i.e., scintillation).

*(Note: references noted are not provided with this document but are available with the original text.)

(b) Restricted field-of-view and minimal resolution.

(c) Degraded depth perception at distances of greater than 500 feet.

(d) Inability to read cockpit instruments without manually refocusing the system.

(e) Frequent battery failures.

(f) A total system weight and forward center of gravity of the NVG and flight helmet combination which caused excessive strain of neck muscles and cheeks.

(g) Incompatibility with standard cockpit lighting.

These performance shortcomings were addressed by modifying the AN/PVS-5 NVG's and peripheral equipment (e.g. cockpit lighting) and by teaching aircrew techniques to compensate for technological limitations. The NVG modifications included cutting away the lower faceplate, adding a dual battery pack with a switch for selecting a fresh battery if one failed, and designing a new mount for the intensification tubes. These changes allowed a better view of cockpit instruments and permitted reading of maps, checklists, etc., without refocusing the NVG's. In addition, the reduced weight was more comfortable and battery failures were easily corrected. With the use of an infrared "pink light" filter installed on the aircraft search light, flight operations could be conducted at ambient light levels below 1/4 moon illumination. Cockpit lighting modifications allowed aircrews to easily read instruments without the illumination causing the NVG's to whiteout. Compensation for the restricted field-of-view and degraded depth perception was accomplished by instructing aircrews to recognize appropriate visual cues for determining aircraft position and rate of closure relative to obstacles. The USAARL tests substantiated earlier evaluations that the AN/PVS-5 NVG's were operationally effective and concluded that the modifications made to the NVG's enhanced their effectiveness.

The U.S. Marine Corps and U.S. Navy accepted the results of the Army's testing and began fielding AN/AVS-6's in 1987. This was effective as the AN/AVS-6 out performed the AN/PVS-5 (reference 18, appendix C).

(2) AN/AVS-6

Initial developmental tests on the AN/AVS-6 NVG's were conducted in mid-1981 by the U.S. Army Aviation Development Test Activity, Ft. Rucker, Alabama, and the Electro-Optics Laboratory, Ft. Belvoir, Virginia (references 19-23, appendix C). These tests included nap-of-the-earth flight, nonstandard maneuvers, night weapons firing, and visual acuity. Tests were also conducted in cold weather, tropic, and desert environments. The AN/AVS-6 goggles were rated significantly better in all areas than the AN/PVS-5 goggles because of three general areas of improvement:

(a) Increased comfort due to reduced weight and better weight distribution.

(b) Better design allowing greater peripheral vision.

(c) Improved optics for greater resolution and acuity, especially at low light levels, and increased resistance to bright light whiteout.

The restricted field-of-view and degraded depth perception were still shortcomings. Compensation for these NVG technological limitations was accomplished by instructing aircrews to recognize appropriate visual cues for determining aircraft position and rate of closure relative to obstacles.

Operational tests on the AN/AVS-6 were conducted beginning in 1981 by the Army, 1982 by the Navy, 1983 by the Air Force, and 1987 by the Marines (references 18, 24-29, appendix C). Each test concluded that the AN/AVS-6 NVG's were operationally effective as a night vision aid.

NVG Capabilities and Limitations Addressed in Training U.S. Army

Preparation for formal training of Army aircrews began with the publication of training circulars in 1976 and initiation of instructor pilot training in 1977. The first initial entry rotary wing class began familiarization training with AN/PVS-5 aviation NVG's in January 1978. NVG qualification training was performed in field units until 1983 when the qualification program was added to the institutional training program at Ft. Rucker, Alabama. Some Army units still perform NVG initial qualification training. Training support packages which contain standardized NVG flight training procedures, prepared at Ft. Rucker, are sent to these units. Refresher courses for aviators returning to flight duty from non-flying assignments require NVG qualification or re-qualification. Additional training is performed in each unit prior to a pilot been authorized to fly an NVG mission or perform pilot-in-command duties. Training is conducted principally with the AN/PVS-5. As units become equipped with the AN/AVS-6, training is conducted with these goggles.

To complete NVG qualification training, an Army aviator must pass an evaluation consisting of an oral examination and a flight examination. The pilot must answer questions on topics which include, operating limits and restrictions, emergency procedures, and aeromedical factors. Wearing NVG's, the pilot must successfully perform flight tasks such as hover, take-off, traffic pattern, terrain flight (nap-of-the-earth, contour or low-level) procedures, and confined area operations.

The Directorate of Evaluation and Standardization from Ft. Rucker conducts flight evaluations worldwide to ensure quality and the standardization of unit aviators and instructor pilots. The NVG evaluations have an average success rate of 97% for FY86-88.

The Flight Training Guides for each aviator course, Training Circular 1-204, and mission planning checklists each thoroughly discuss NVG capabilities and limitations (References 30-35, Appendix C). Procedures and techniques for reducing the training programs are re-emphasized in refresher and continuation training.

U. S. Air Force

In the Air Force, Special Operations and Rescue units have used some type of passive night vision device since the qualification programs. Beginning in the early 1980s, the tactical application of NVG's for both fixed-wing and helicopters was significantly expanded. Since then, Air Force helicopter pilots have received initial NVG qualification training with the Army at Ft. Rucker. Additional NVG training is provided during transition into the assigned helicopter type and in the assigned unit before pilots are considered qualified for the unit mission. Fixed-wing aircrews are NVG qualified exclusively in their units.

Air Force pilots are required to pass an oral and flight evaluation prior to being NVG qualified. The tasks a pilot must demonstrate include an understanding of NVG capabilities and limitations, mission planning procedures, crew coordination procedures, en route and terminal area operations, response to simulated emergencies, formation flight and air refueling procedures.

Major Command (MAC and SAC) regulations, training directives and pre-mission checklists each emphasize NVG capabilities and limitations (References 36-39, Appendix C). Aircrews (pilots, flight engineers, aerial gunners, etc.) are taught the procedures and techniques that reduce the impact of NVG limitations on night flight operations.

The Air Force Inspector General is conducting a Functional Management Inspection on NVG's. The inspection will review acquisition, training, maintenance and aeromedical aspects of NVG operations. A report on their findings will be completed by August 1989.

U. S. Marine Corps

Helicopter pilots are the principal users of NVG's in the Marine Corps. Training with the AN/PVS-5 NVG's began in 1977.

APPENDIX C
DOCUMENTS AND VIDEOTAPES OBTAINED DURING EVALUATION

1. "Emergency Medical Services/Helicopter," FAA Advisory Circular 135-14, 20 October 88.

2. "Development History of the AN/PVS-5 Night Vision Goggle Night Vision & Electro Optics," Ft. Belvoir, VA, 26 May 89.

3. "GM-6 AN/PVS-5 NVG Mount and AA Battery Pack Evaluation Marine Helicopter Squadron One," Quantico, VA, 4 August 88.

4. "Comparative Visual Performance with ANVIS and AN/PVS-5A Night Vision Goggles under Starlight Conditions," August 84.

5. "Coast Guard Night Vision Goggle Designation/Currency Requirements Aviation Training Criteria," Mobile, AL.

6. "Night Vision Device Training for Nonrated Crew Members," Night Vision Systems, Aviation Training Brigade, Ft. Rucker, AL, 11 August 89.

7. "Initial Night Vision Goggles Training Requirements," Night Vision Systems, Aviation Training Brigade Ft. Rucker, AL, 30 August 1989.

8. "Nite Lab, Night Imaging and Threat Evaluation Lab," Yuma, AZ,.

9. "NVG Preflight Calibration Lane, Night Imaging and Threat Evaluation Lab," Yuma, AZ.

10. "Standard Operating Procedures (SOP) for Pacific Fleet USN/USMC NVG Shipboard Operations," 24 July 89.

11. "Human Factors and Safety Considerations of Night Vision Systems Flight," Office of the Program Manager for Night Vision and Electro-Optics, Ft. Belvoir, 22060 Robert W. Verona, Clarence E. Rash, July 89.

12. "Helicopter Flights with Night Vision Goggles - Human Factors Aspects." Michael S. Brickner, National Research Council.

13. "Night Flight Techniques and Procedures," TC-1-204, U.S. Army Aviation Training Center, Ft. Rucker, AL, December 88.

14. "Night Vision Goggle Manual," Marine Aviation Weapons and Tactics Squadron One, Yuma, AZ, 15 April 88.

15. "Night Optical Device Training Program (Draft)," Rocky Mountain Helicopters, Inc.

16. "U.S. Coast Guard HH-3F Standard Night Vision Goggle Syllabus Instruction," U.S. Coast Guard Aviation Training Center, Mobile, AL, 7 February 89.

17. "User's Guide and Software for NIGHTVIS Computer Program (Draft)," David Santen, U.S. Army Atmospheric Sciences Laboratory, White Sands Missile Range NM, 1987.

18. "Review of Testing Performed on AN/PVS-5 and AN/PVS-6 Aviation Night Vision Goggles," Office of the Director Operational Test and Evaluation, Office of the Secretary of Defense Washington, DC 20301, 30 January 89.

19. "Rationale Behind the Requirements Contained in Military Specifications MIL-L-8562 and MIL-L-85762A," Ferdinand Reetz III, Naval Air Development Center, Warminster, PA 18974-5000, 17 September 87.

20. "Night Vision Flying - A Special Report to the Field U.S. Army Safety Center."

21. "Lighting, Aircraft, Interior, Night Vision Imaging System Compatible, MIL-L-85762A," System Engineering and Standardization Department, Naval Air Engineering Center Lakehurst, NJ 08733, 26 August 88.

22. "Flightfax, Report of Army Aircraft Mishaps," Vol 15, No. 47, Can you see, are you sure? U.S. Army Safety Center. Maj Ron Isbal., 1215 S 52nd Street, 2 September 87.

23. "Litton Image Intensifiers," Litton Electron Tube Division, Tempe, AZ 85281.

24. "Aviation Night Vision Goggle Perspective," Briefing charts from U.S. Army Safety Center, Ft. Rucker, AL 36362.

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VIDEOTAPES

A. U.S. Coast Guard Initial NVG Qualification Training Video - NVG Physio Optics
B. "The Night Environment"
C. "ANVIS"
D. U.S. Coast Guard Terrain Board
E. Litton Night Vision Devices